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SOCIETY AND RELATED ACTIVITIES

New Members—November 1933

Class "B"	*Proposed by*
E. P. S. Gardner—Quasi-Arc, Inc., P. O. Box 54, New Brunswick, N. J.	J. J. Crowe
Y. Matsuda—Imperial Japanese Naval Inspector's Office, 1 Madison Ave., New York City	
J. W. Allison—Westinghouse E. & M. Co., 30th & Walnut Sts., Del. County, Pa.	R. D. Thomas
Class "C"	
Eugene V. Mingotte—81 Addison Street, E. Boston, Mass.	
H. O. T. Ridlon—Barrett Hardware Co., Joliet, Ill.	
Wm. G. Allen—American Twist Drill & Tool Co., 2804 W. Jefferson, Detroit, Mich.	
Inge Lyse—Lehigh University, Bethlehem, Pa.	W. Spraragen
Class "D"	
A. T. Rudd—White's Garage, W. Ossipee, N. H.	
Class "F"	
E. F. Potter—2240 William Street, Schenectady, N. Y., General Electric Co.	R. W. Clark

Ford Exposition of Progress

Port Authority Commerce Building
8th Ave. & 15th St.

More than 150 industries will be represented in the biggest show ever held in New York City, according to officials of the Ford Motor Company, who announced yesterday that they will hold a Ford Exposition of Progress in the Port Authority Commerce Building in New York City beginning on December 9th. The exposition will require six acres of floor space and will utilize more than 10,000 tons of equipment.

More than 150 industries are cooperating with the Ford Motor Company. In addition to depicting the history of the motor car through exhibits of early model automobiles, the exposition will provide the public with a graphic picture of what the country's various industries have done to develop the automobile industry.

The Bethlehem Steel Company will actually manufacture steel at the exhibit and the Briggs Manufacturing Company will turn out twenty completed automobile bodies daily. Tremendous stamping presses and electric welding equipment are being installed in the Port Authority Building to make it possible for the public to witness the manner in which steel motor car bodies are made. In sharp contrast to the modern scientific developments which will be shown will be the original workshop of Henry Ford.

The rubber industry will be represented and the United States Rubber Company will have a miniature Sumatra rubber plantation with living rubber trees. The public will see the milk gathered from the trees and will be able to witness the complete operation of tire manufacturing. The Firestone and Goodrich companies will supplement this with extensive exhibits of their own.

The exposition will also show a number of scientific devices, including a 280,000-volt X-ray device by means of which the public will have an opportunity to peer through solid steel. Electric eyes will count parts as they pour from a machine and the stroboscope will do its work. This novel device by optical illusion slows down a motor which is turning thousands of revolutions per minute and makes its parts look as though they were barely turning. Another unusual device will be the acoustimeter, with which the listener can hear only those sounds he wishes to hear. Other sounds are tuned out.

"The Book of Stainless Steels"

A gap in the field of technical literature has been filled with the publication of "The Book of Stainless Steels" by the American Society for Steel Treating.

Seventy-seven authorities on making and using the many kinds of heat and corrosion-resisting chromium alloys collaborated to write this book.

About two-thirds of the chapters describe the properties of the steels—how to fabricate them and what to expect of them.

"The Book of Stainless Steels" has 614 pages of text and 200 illustrations, including photographs, charts and diagrams. It is bound in red cloth and is 6 by 9 inches. Price is $5.00, post paid. Orders may be sent to the AMERICAN WELDING SOCIETY.

Arc Welding Abroad

The August 4, 1933, issue of "The Engineer," in summarizing matters discussed at the recent Scandanavian World Power Conference, makes the following reference to welding:

"Professor Kuchel (Germany) in his report (No. 70) drew attention to the immense strides made in the application of electric welding processes. In Germany, he said, the present energy consumption for electric arc welding alone was at least 50 million kwh. annually, and Mr. Hansson noted that there were about 10,000 welding sets in use today in that country, and that the tendency in arc welding was toward an increased use of alternating current. In regard to resistance welding the present development was mainly concerned with the design of automatic apparatus."

Obituary

The Society learns with regret of the passing away of William Penn Brown on October 31st at Oakland, California, after a lingering illness of two years.

Mr. Brown at the time of his death was Vice-President and General Manager of Brown Bros. Welding Works of San Francisco, one of the largest and most up-to-date welding shops on the Pacific Coast.

Mr. Brown was a graduate of Yankton College, Yankton, S. D., and of the Minnesota University, where he became interested in oxyacetylene welding and cutting. Since 1911 he was successively connected with the Metal-Weld Company, the Brown Bros. Welding Works and the National Welding & Equipment Company.

William Brown and his brother Hugh were charter members of the San Francisco Section of the AMERICAN WELDING SOCIETY, of which organization William Brown was one of its first chairmen. He was well known in marine circles on the Pacific Coast since the Brown Bros. Welding Works pioneered welding repairs on steamships visiting the port of San Francisco.

Besides his widow, Laura E. Brown, he leaves two sons, Howard and Robert, and a daughter, Frances.

RESOLUTIONS:

At the regular monthly meeting of the San Francisco Section of the AMERICAN WELDING SOCIETY held in Alameda, California, on November 24, 1933, the following resolutions were adopted:

WHEREAS, the AMERICAN WELDING SOCIETY has learned with profound sorrow of the passing of William Penn Brown, October 31, 1933.

WHEREAS, in the death of William Penn Brown, the San Francisco Section of the AMERICAN WELDING SOCIETY has lost a charter member, a pioneer in the art of welding, a man of vision and enthusiasm, a business associate of integrity and honor, a loyal co-worker for the advancement of the welding industry, a helpful and intelligent counsellor and a man whose sterling character will long be remembered by those whose good fortune it was to know him; therefore, be it

RESOLVED: That the AMERICAN WELDING SOCIETY hereby expresses the deep regret of its members in his death, and that the Society honors the memory of Mr. Brown and expresses its deep sorrow for his loss by incorporating this resolution in the records of the Society and sending copies to his bereaved family and business associates as evidence of its compassion.

SECTION ACTIVITIES

BOSTON

One of the most instructive and interesting meetings the Boston Section has ever held was the meeting of November 3, 1933, at the Watertown Arsenal. This was a joint meeting with the Boston Chapter of the American Society for Steel Treating, and the two Societies were well represented—attendance being 400. The details of this program are given below.

Afternoon Session

Subject	Demonstrator
Induction furnace melting and centrifugal casting of cannon	Lt. Conner
Cold working of cannon	Lt. Latimer
High temperature anneal, hardening and tempering centrifugal castings	Lt. Mesick
Demonstration at assembly table in connection with talk on design for welding	Mr. Healy and Mr. Maguire
Demonstration of completed gun, going in action, in action and going out of action	Mr. Maguire
Physical testing. Impact test	Mr. Mann
Stress-strain curves	Mr. Mann
Macro study of etched steel	Dr. Yatsevitch
X-ray study of welded structures	Dr. Lester
Flash and spot welding	Mr. Maguire
Gas cutting of weld plate with templates	Mr. Maguire
Exhibit of welded joints	Mr. Warner

Evening Session

Dinner—entertainment
Routine Society business
Presentation of prepared papers:
"The Development and Functions of the Arsenal," Col. Jenks, Commanding Officer.
"Welding of Structural Nickel Steel," Mr. W. L. Warner.
"Centrifugal Casting," Lt. S. L. Conner.
"Heat Treatment of Centrifugal Castings," Col. G. F. Jenks.

The next meeting of the Section will be held Friday evening, December 8th, in Room 4-270 at the Massachusetts Institute of Technology at 7:45 P.M. The papers to be presented are: "Some Metallurgical Aspects of Welding," by Dr. J. P. Walsted of M. I. T., Chairman of Boston Branch, Fundamental Research Committee of American Bureau of Welding; and "Nitrogen in Welds," by Prof. J. H. Zimmerman, of M. I. T. Both papers will be illustrated.

CHICAGO

The Chicago Section held its first meeting of the season Friday evening, November 24th, at the Wedgewood Hotel. The subject of this meeting was "The N. R. A. as It Affects the Welding Industry." The speakers for the evening were T. B. Marshall, from the office of the District Compliance Director of the N. R. A., and T. S. Wright, of the Hollup Corporation.

After the talks there was considerable discussion upon the subject by a number of the members and guests. There were about sixty members and guests in attendance.

The next meeting will be held Friday evening, December 14th, and the subject of this meeting will be "Recent Developments in Structural Welding."

DETROIT

The December meeting of this Section will be held on the 14th. G. E. Phelps, of the Air Reduction Sales Company, is scheduled to read a paper on "Flame Machining by the Oxyacetylene Process."

LOS ANGELES

An interesting, instructive and entertaining meeting of the Los Angeles Section was held on November 23rd in the Chamber of Commerce Building. The program was as follows:

"Recent Advances in Electrical Sciences," by G. M. Hawley, S. L. Cipperly and G. M. Rankin, all of the Southern California Edison Company.

Mostly All Action—Not Much Talk: (1) "The Electric Eye"; (2) "Invisible Light"; (3) "Black Light"; (4) "Transmission of Sound over Light Beams"; (5) "Light and Color" by Mr. G. M. Rankin; (6) "Death Rays."

Actual electrical demonstrations were given which could be seen as well as heard.

PHILADELPHIA

The November 20th meeting of this Section was well attended. Mr. W. D. Halsey, Assistant Chief Engineer, Boiler Division, Hartford Steam Boiler Inspection & Insurance Co., gave an excellent talk on the Boiler Code, and the discussion which followed was quite lively.

The next meeting of this Section will be held on January 15th with the following program: Mr. O. A. Tilton, Industrial Engineering Dept., General Electric Company, will talk on "Hard Surfacing by Welding." Mr. E. V. David, Applied Engineering Dept., Air Reduction Sales Company, will talk on "Armoring Machinery and Equipment to Resist Wear."

NEW YORK

An unusually successful symposium was held by the New York Section on November 22nd on Aluminum Welding. About 350 people were present. The following papers were presented:

General Lecture, by Dr. H. V. Churchill, Chief Chemist, Aluminum Company of America.

"Arc Welding and Electric Resistance Welding of Aluminum," by D. I. Bohn, Aluminum Company of America.

"Gas Welding of Aluminum," by G. O. Hoglund, Aluminum Company of America.

PITTSBURGH

The next regular meeting of the Pittsburgh Section will be held Wednesday night, December 6th, in the Tudor Room, Fort Pitt Hotel, Pittsburgh.

The speaker for this occasion will be J. C. Hodge, Engineer of the Babcock & Wilcox Company, Barberton, Ohio.

Mr. Hodge will deliver a paper on the "Fabrication of Penstocks by Fusion Welding for Boulder Dam" and will discuss briefly the Boulder Dam Project. Both slides and films will be shown.

SAN FRANCISCO

A very excellent program was arranged for the November 24th meeting of the San Francisco Section which was held in the auditorium of the Alameda High School. Mr. Charles Cox, Director of Vocational Education, Alameda, showed a sound film demonstrating the various and sundry things which can be accomplished by proper control of sound, inspection of the unusually fine school ships and an explanation of one of the most outstanding school broadcasting installations in the country.

Mr. L. W. (Duke) Evans of the Richmond Plant of Rheem Manufacturing Company spoke on "Production Welding."

Mr. C. S. Smith, District Manager of Linde Air Products Company, Pacific Coast, presented a paper on "Maintenance of Plant Equipment."

Mr. C. R. Owens of the General Electric Company, showed an interesting film on pipe welding.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-206. Welding engineer with mature judgment of design for welding, experienced in welding of heavy machine parts, structural work, hand, automatic and carbon welding of light gage steel and everdur tanks, interested also in employment as welding foreman or any temporary assignments to assist with weld design or establish economical welding.

A-207. Arc welder desires position. Forty years of age. Desires steady work. Has six years' experience in general hand arc welding and is mechanically inclined. Have also experience in machine shop and gray iron foundry work. Have experience also as arc-welding foreman and inspector.

The Metal-Arc Welding of Galvanized Steel

By LEON C. BIBBER

†Paper was presented at Fall Meeting, A. W. S., Detroit, October 2nd to 6th, by Leon C. Bibber, Senior Welding Engineer, Bureau of Construction and Repair, Navy Department, Washington, D. C.

1. Introduction

IN NAVAL ship construction, particularly on the lighter vessels, much of the hull below the 10-ft. waterline is galvanzied and most plating 1/4 in. thick and thinner, which is exposed to weather or water, is likewise protected. Accordingly, we are confronted with the problem of welding galvanized structural members. Only very seldom is it possible to galvanize assembled parts after welding.

In order to study the welding of galvanized material, independent experiments were conducted by the Bureau of Construction and Repair at Washington, and by the Navy Yard at Brooklyn, N. Y. The experimental work, however, did not cover piping nor sheet metal; the thinnest member used was 1/8 in. thick. Of course, the results which will be shown later are applicable to galvanized steel, whether it be structural or piping.

The problem of welding galvanized material is divided into three parts:

(*a*) The effect of the welding on the galvanizing.
(*b*) The effect of the galvanizing on the weld.
(*c*) The physiological effect of the zinc fumes on the health of the welders.

In this paper it is proposed to deal at some length with the first two aspects of the problem; the third is very important but the writer does not feel competent to give it the consideration it deserves. It is hoped that in the discussion some interesting information on this phase will be brought out.

2. Objects of Tests

The many objects of these tests were as follows:

(*a*) To determine the plate thickness at which the galvanizing would be burned from the back as well as the weld side of the plate.
(*b*) To determine the corrosion resistance of a galvanized plate after the galvanizing has been apparently burned off by the heat of welding.
(*c*) To ascertain the degree to which the zinc burns off.
(*d*) To determine whether covered electrodes burn off the zinc coating to a greater extent than bare electrodes.
(*e*) To determine whether multiple bead welding burns off the zinc to a proportionally greater extent than the single bead welding.
(*f*) To determine the effect of the galvanizing on the porosity of the weld.
(*g*) To determine the effect of the galvanizing on the strength of the weld.
(*h*) To determine the relative corrosion resistance of bare and covered electrode welds.
(*i*) To determine the relative corrosion resistance of different sizes of welds, that is, single and multiple bead welds.

3. Specimens

(*a*) General description.

Beads were deposited on a series of galvanized plates with thicknesses varying from 1/8 in. to 1/2 in. by bare and covered electrodes to determine the thickness at which the galvanizing burned off the back of the plate as well as the front. The details of these plates are given in Fig. 1 and the appearance of a typical plate after welding is shown in Fig. 2.

Another series of galvanized plates had galvanized flat bars attached to them by various sizes of bare and covered electrode fillet welds. These welds simulated the attachment of transverse frames and bulkheads to shell and deck plates. In order to determine the effect of bad fitting the bars were held away from the plates so that under the salt spray the salt atmosphere could get in between the plate and the bar and show what, if any, corrosion was taking place there. A detail of these specimens is shown in Fig. 3. The appearance of a typical finished specimen is shown in Fig. 4. The welds varied in size from 3/16 in. to 5/8 in.

A series of lap joint specimens was also made at Brooklyn on plate varying in thickness from 1/4 in. to 1/2 in. with single- and double-layer welds deposited with bare wire.

(*b*) Material.

The plates upon which the welds were deposited were medium steel. The electrodes were commercial bare and covered medium steel. No chemical or physical analyses were made on any of the base material in this test. All galvanizing was done by the hot-dip process and Navy specifications require that the coating shall weigh not less than 2 oz. per sq. ft., nor more than 2 2/3 oz., and that the zinc shall be 98% pure. It will be shown later that the thicknesses of the coatings were much greater than this, however.

(*c*) Welding.

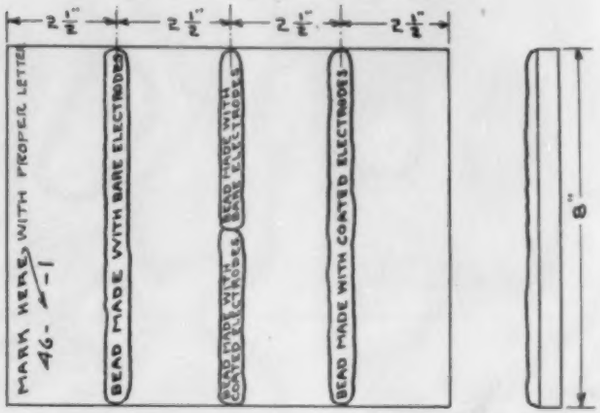
The details of the welding used on the bead-welded specimens are given in Table 1. The details of the

Table 1—Details of Welding Beaded Specimens

Where made: C.&R. welding shop, Navy Yard, Washington, D. C.
Name of welder: F. K. Davis
Preheating: None
Subsequent heat treatment: None
Hammered: No
Position of welding: Flat
Electrode make: bare —; covered —
Electrode grade: bare U. S. Navy department EB; covered U. S. Navy department EA
Polarity: bare Straight; covered Straight
Sequence used: Continuous

Specimen Number	Thickness of Plate, In.	Bare Electrode Beads: Dia. of Electrode, In.	Arc Volts	Amperes	Watts in Arc	Covered Electrode Beads: Dia. of Electrode, In.	Arc Volts	Amperes	Watts in Arc
46-A-1	1/4	1/8	16	80	1280	5/32	26	80	2080
46-B-1	3/16	1/8	16	80	1280	5/32	26	90	2340
46-C-1	1/4	1/8	17	75	1275	5/32	26	90	2340
46-D-1	5/16	5/16	22	160	3520	3/16	35	100	3500
46-E-1	5/8	5/16	22	160	3520	3/16	35	100	3500
46-F-1	1/2	5/16	22	160	3520	3/16	35	100	3500

Fig. 1—Details of Bead-Welded Specimens



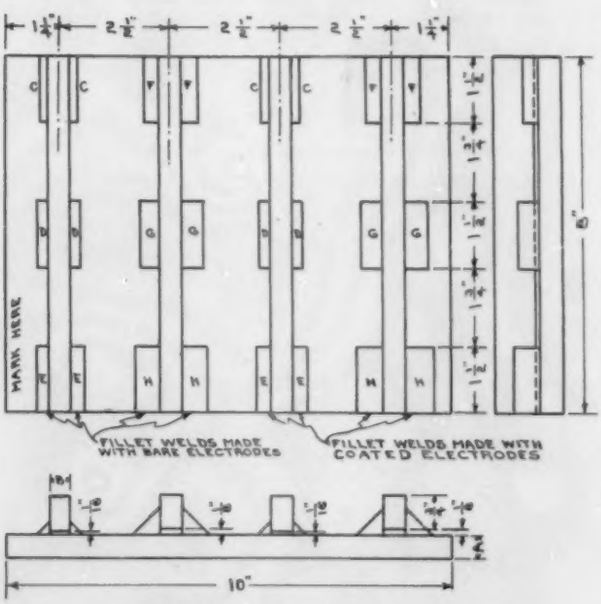


Fig. 3—Details of Fillet-Welded Specimens

welding used on the fillet-welded specimens are too voluminous for inclusion here, and only the two extreme cases are shown in Table 2, namely, for $^1/_8$-in. and $^1/_2$-in. plate.

4. Apparatus

The specimens were tested for corrosion resistance in a U. S. Navy standard salt spray bath. The details of the construction of this bath are given in Fig. 5, and the appearance of the bath with the specimens installed is shown in Fig. 6. The specimens were set in notches in wooden racks and not suspended as shown in Fig. 5. The spray generated by means of the atomizers shown in Fig. 5 was composed of a 4% sea salt solution in these tests. A 20% sodium chloride solution is now generally used, however.

5. Effect of Welding on Galvanizing

When a galvanized plate such as is shown in Fig. 2 is welded, the plate surface becomes covered with dirt and spattering, and white zinc fumes rise profusely. The zinc on the back of the plate also burns and the yellow flame can be watched as it follows the progress of the arc. The burning of the zinc on the reverse side is shown in Fig. 7. Here the heat of the arc was so great that the plate has also melted in one case. In Fig. 2 is shown the plate after the dirt had been carefully cleaned off with a wire brush. The extent to

Fig. 2—Bead-Welded Specimens $^1/_4$ In. Thick—Obverse Side

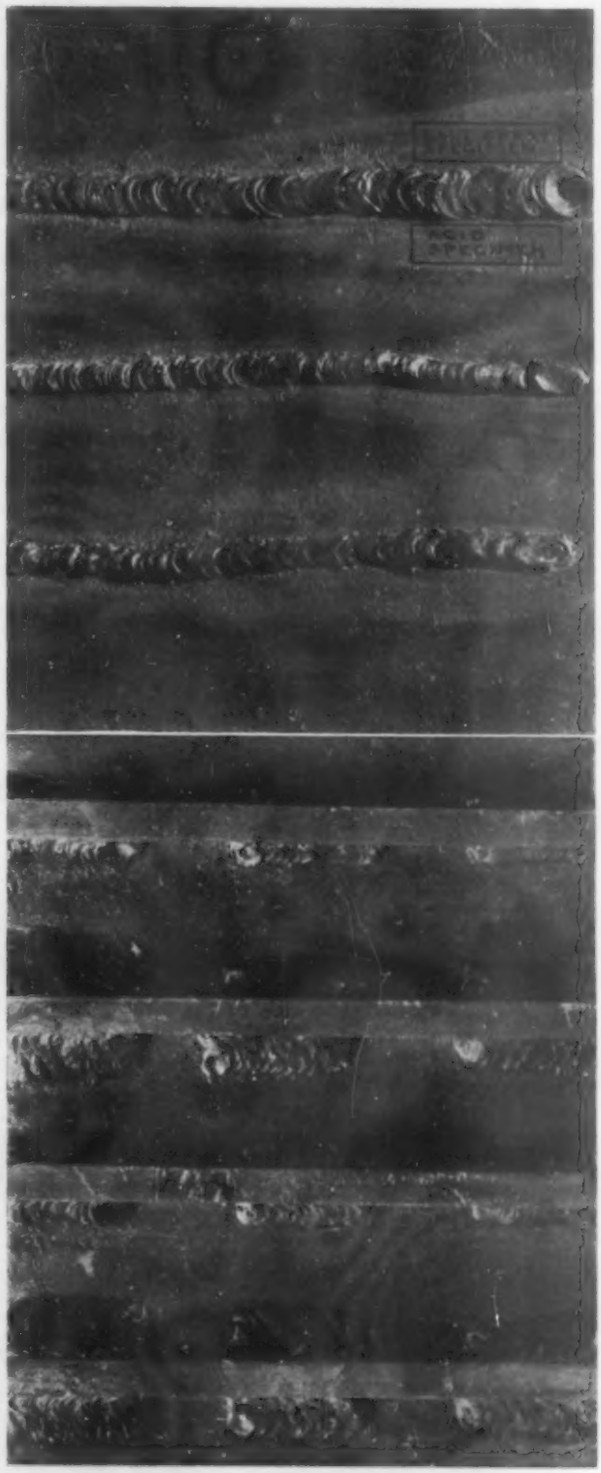


Fig. 4—Fillet-Welded Specimens

Table 2—Details of Welding, Fillet-Welded Specimens

Specimen Number	Thickness of Plate, In.	Fillet Welds: Designation	Size, In.	Number of Layers	Electrode: Bare or Covered	Dia., In.	Arc Volts	Amperes	Watts in Arc
		C	3/16	1		1/8	15	75	1125
		D	3/16	1		1/8	16	65	1040
		E	3/16	1	Bare	1/8	16	65	1040
		F	1/4	1		1/8	16	65	1040
		G	1/4	1		1/8	14	65	910
		H	1/4	1		1/8	16	65	1040
46-A	1/8	C	3/16	1		5/32	24	80	1920
		D	3/16	1		5/32	24	80	1920
		E	3/16	1	Covered	5/32	24	80	1920
		F	1/4	1		5/32	24	75	1800
		G	1/4	1		5/32	24	75	1800
		H	1/4	1	"	5/32	24	75	1800
		C	3/16	1		1/8	18	90	1620
		D	1/4	1			22	140	3080
		E	5/16	1	Bare		22	140	3080
		F	3/8	2		3/16	22	140	3080
		G	1/2	2			22	140	3080
46-L		H	5/8	3			22	140	3080
46-M	1/2	C	3/16	1			26	75	1950
46-N		D	1/4	1			26	75	1950
		E	5/16	1	Covered	5/32	26	75	1950
		F	3/8	2			26	75	1950
		G	1/2	2			26	75	1950
		H	5/8	3			26	75	1950

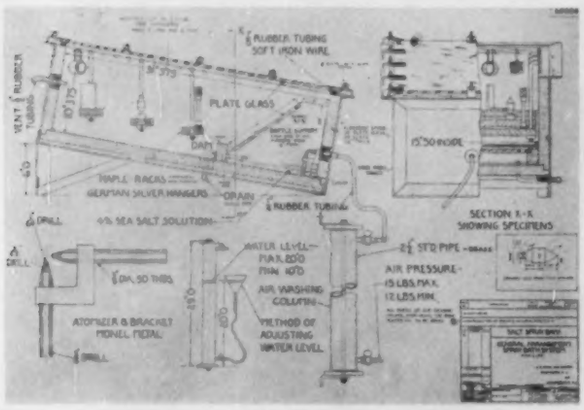


Fig. 5—Navy Standard Salt Spray Apparatus

which the zinc has melted can be clearly seen due to the polish caused by the wire brushing on the unmelted zinc. The galvanized coating has been melted back for an inch or so in the case shown, but in some instances melting actually extended to the edge of the plate. It was found that wire brushing could not be started too soon or the brush would drag through zinc that was still soft.

The series of beaded plates was made to determine at what thicknesses the coating on the reverse side would be melted. It will be noted from Table 1 that varying electrode sizes were used for varying thicknesses of plates. It will not be necessary to show the reverse side of all plates. The results of these tests are as follows:

(*a*) Both bare and coated electrodes will melt the zinc on the reverse side of a plate 3/8 in. thick. On a plate 1/2 in. thick the reverse surface of the zinc assumed a somewhat dull appearance, but the characteristic melted appearance shown in Fig. 7 did not occur. One-half inch plate may, therefore, be considered as

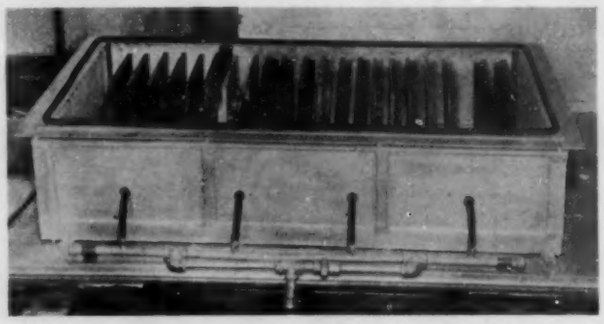


Fig. 6—Specimens in Salt Spray before Closing Tank

about the minimum thickness at which normal welding will not burn the zinc on the reverse side. This result was also corroborated on the multiple beaded fillet-welded specimens.

(*b*) The covered electrode causes a greater burning off of the zinc, but not to the same degree as would be expected from the wattages in the arcs as shown in Table 1 due to the greater speed of the former.

The extent to which the coating burned off of the thinner plate was somewhat surprising. It was not expected that the zinc would be melted to a distance of an inch or more from the toe of the weld, but this fact

Fig. 7—Reverse Side of Bead-Welded Specimen Plate 1/4 In. Thick

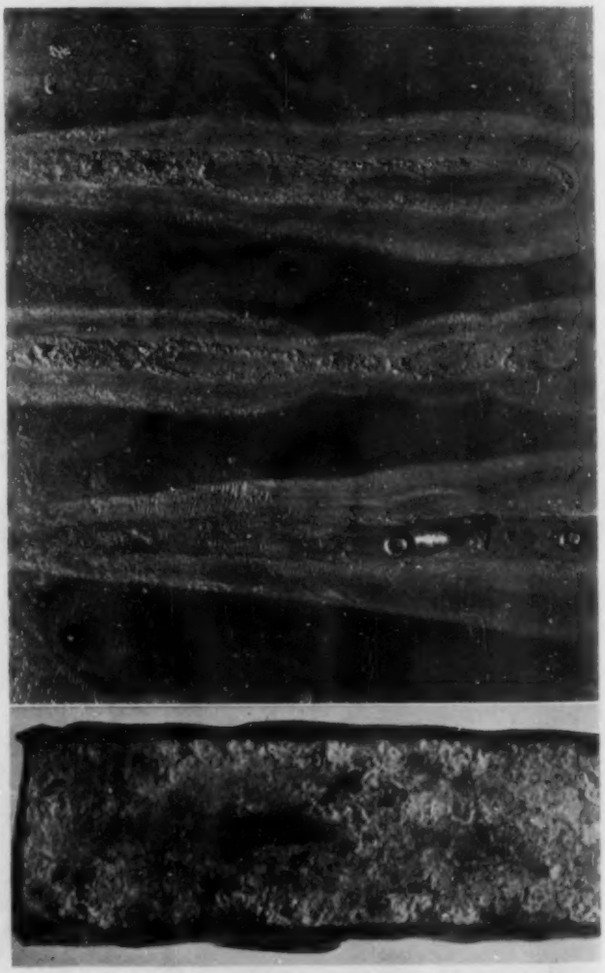
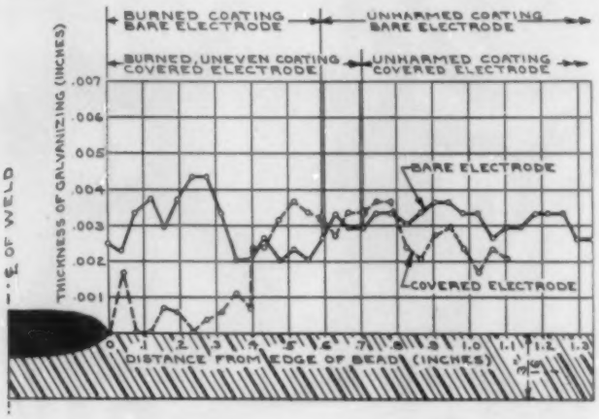


Fig. 8—Salt Spray Specimen from Burnt-Off Part after 1100 Hrs. in Spray

Fig. 9—"Burning Off" of Galvanized Coating from 3/16-In. Plate



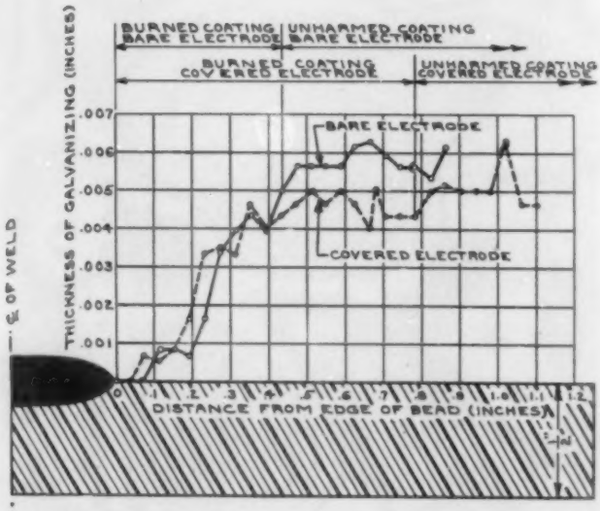


Fig. 10—"Burning Off" of Galvanized Coating from ½-In. Plate

made it possible to conduct some interesting investigations on the burnt-off parts.

A section about 1/2 in. x 2 in. was cut from the burnt-off zone about as shown in Fig. 2. The rough saw-cut edges were coated with bee's wax to prevent rust from running down over the galvanized part, and then the specimen was subjected to the salt spray for 500 hrs.

In order to give an idea of the efficacy of this method of testing it might be stated that 500 hrs. in the spray will cause a breakdown of one coat of paint, and 1100 hrs. will cause a general breakdown of two coats.

Photographs of salt spray specimens are not very satisfactory because the salt upon crystallizing turns white and obscures the view of the surface beneath. Observations can be made much better when the specimens are wet.

In Fig. 8 is shown the section referred to above, after 1100 hrs. in the spray. The white substance is the salt; the dark spot in the center was caused by rubbing the salt from that spot. Rust stains would show dark on such a picture. After 1100 hrs. in the spray there was no attack whatsoever on this specimen from which the zinc was apparently burned off. It should also be pointed out that this specimen was subjected to the spray by itself, that is, it received no protection from the anodic effect of any neighboring zinc.

A specimen was then cut from the opposite side of the burnt-off portion as shown in Fig. 2. The amount of zinc remaining was determined chemically, and the area of the specimen carefully measured. From the data thus obtained it was found that enough zinc remained on this burnt-off specimen to coat both surfaces with a skin of zinc 0.0027 in. thick.

The above calculation was made on the assumption that the galvanizing coating is pure zinc. This is not strictly true, but is accurate enough for purposes of comparison.

In order to further verify the presence of appreciable quantities of zinc on plate from which the galvanizing has been apparently burned off, transverse specimens across the weld were polished and etched and the thickness of the coating measured with the micrometer attachment on the microscope. The results of these tests are shown graphically in Figs. 9 and 10.

The two-ounce coating required by specification has a theoretical thickness of 0.0035 in. (calculated as above), and the 2 3/8-oz. coating a theoretical thickness of 0.0046 in. It will be seen from Figs. 9 and 10 that on the 3/16-in. plate the average thickness of the unharmed coating is about 0.003 in., while for the 1/2-in. plate the average thickness of the unharmed coating is somewhat thicker, about 0.0055 in. It is probable that this greater thickness is due to the thicker plate not reaching in the bath the temperature attained by the thinner.

It will be apparent from both figures that the coating may or may not be completely burned off at the toe of the weld. The areas in which the measured thickness of the coating was found to be zero were, however, very small. The coating increased rapidly in thickness to the point where the zinc was unharmed. So it can be seen that in the zone where the zinc has been melted there are still appreciable quantities of zinc.

In general, the coating is burned off to a greater extent with the covered electrode and the zinc has been melted at a greater distance from the weld. This is about as might be expected.

A photomicrographic study was also made of coating in way of the welding.

In Fig. 11 is shown as photomicrograph of an unharmed zinc coating. According to Finkeldey,* this coating is comprised of an upper layer of pure zinc which shows light colored in the photograph, and a lower layer of zinc-iron compounds which are the darker colored constituents next to the base metal. The formulae $FeZn_3$ and $FeZn_7$ have been assigned to different layers of this latter zone. These formulae are not believed to be exact, but they are sufficiently so for all practical purposes.

In passing it is of general interest to note in Fig. 11 the keying of the zinc coating to the steel. The pickling acid eats out pits and the zinc keys itself into them. The existence of thousands of these keys explains why a zinc coating adheres so tenaciously.

In Figs. 12 and 13 are shown the coatings in the burnt-off portion. Save for a small amount of light-colored constituents in Fig. 13, all of the coating seems to have been transformed to zinc-iron alloy, or the pure zinc upper layer has been burned off and the zinc-iron compounds left behind. In the left-hand part of Fig. 12 it will be seen that the coating has been much reduced in thickness.

In view of the above it is apparent that, even though the coating may have been melted for a considerable distance from the toe of the weld, there is only a very narrow zone at the toe in which no coating can be seen under the microscope. Whether this small area is protected by a coating too fine to be visible or whether the anodic effect of the adjacent zinc protects the

* *Metals & Alloys*, Nov. 1931, p. 266.

"bare" area, is not known. Certain it is, however, that this "bare" area is not attacked as would be steel which had never been galvanized.

6. Effect of Galvanizing on the Welding

In Fig. 14 is shown one of the fillet-welded specimens after 1100 hrs. in the salt spray. As was stated previously, photographs of salt spray specimens are far from satisfactory, but it can be seen in this view that the large multiple beaded fillets show dark rust stains, while the small single bead fillets show little or no rusting. The reason for this is, of course, the fact that in a small single bead weld a certain amount of the zinc fumes sublimates on the hot deposited metal and forms a protective coating or a compound. In a multiple beaded weld the amount of zinc to be volatilized is greatly reduced and the protection becomes progressively less and less.

Analyses were made of the different sizes of fillet welds with the results shown in the following table:

Size of Weld	Zinc Content, % Bare Electrode	Covered Electrode
1/8	0.044	0.052
3/16	0.042	0.055
1/4	0.042	0.058
5/8	0.023	0.058
1/2	0.018	0.063
3/4	0.027	0.042

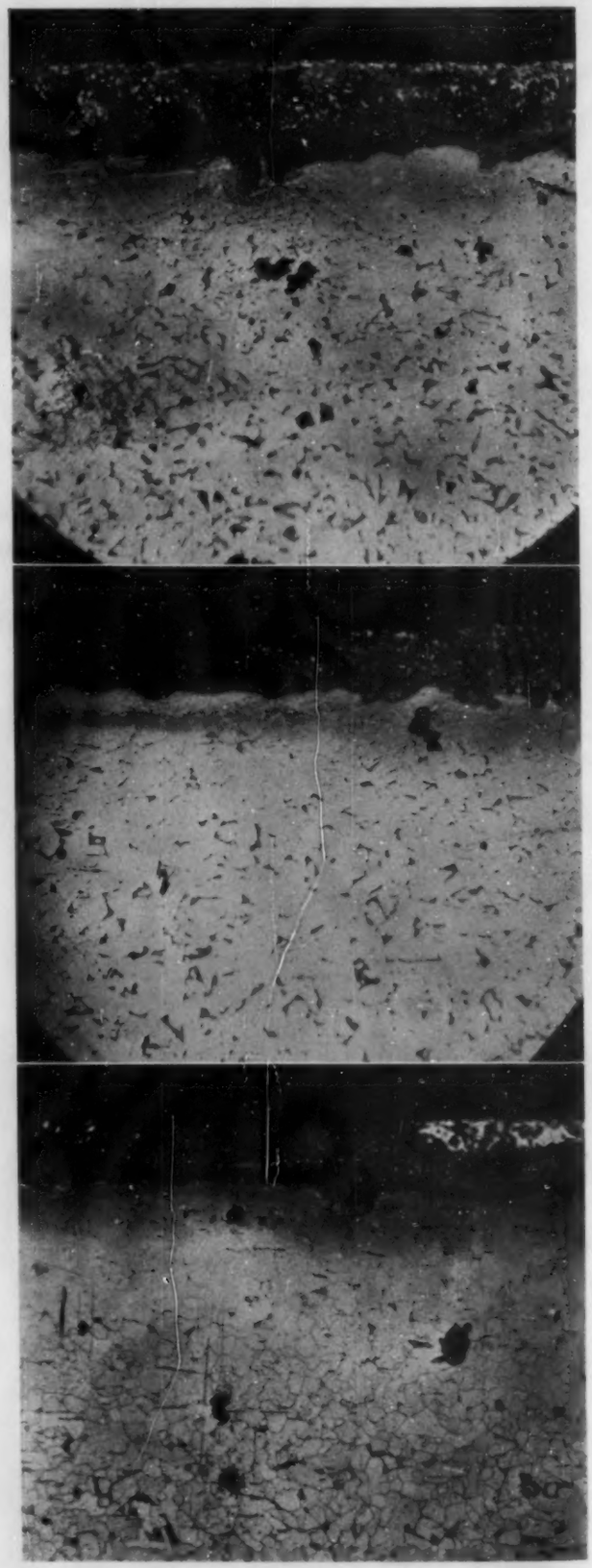
In general, the covered electrode deposits show a slightly greater zinc content than those of the bare wire. This may be caused by the greater amount of zinc melted by the covered electrode. The large multiple beaded fillets also show a lesser zinc content. The above analyses probably do not give a true indication of the amount of zinc actually in the metal itself because the chips milled from the welds would necessarily contain such zinc as was on the surface. In tests conducted at the Brooklyn Navy Yard no zinc was found in weld metal.

It was not possible to decide from the salt spray specimens which was superior, as regards resistance to corrosion, the bare-wire deposits or the covered wire. Both seemed to show rust stains to about the same degree.

It has been held that welding on galvanizing causes increased porosity in the deposit. In order to check this point the fillet-welded specimens were sawed through in such a manner that the throats of all the different sizes of fillets were exposed. These specimens were then boiled in acid. The results of this examination were not conclusive. The bare-wire deposits did not seem to be any more porous than bare-wire deposits on black steel, and the covered electrode welds were apparently perfectly normal. On the other hand, the tests at Brooklyn indicated greater porosity in single bead welds on galvanized material than would have been the case on black steel. It seems reasonable to expect slightly greater porosity due to the presence of fumes to cause pockets and inclusions. It will be seen in Fig. 14 that no corrosion has taken place in the burnt-off portion of the base metal at the toes of the welds.

In Table 3 are given the results of tensile tests conducted at the Brooklyn Navy Yard on different thicknesses of plating. The welds were all made with bare wire and the joints were all lapped. This type of joint

Fig. 11—Unharmed Zinc Coating at a Magnification of 100 Dia.



Figs. 12 and 13—Microphotographs Showing Burnt-Off Portion of Zinc Coating at a Magnification of 100 Dia.

Table 3—Results of Tests on Welded Galvanized Lapped Joints

Plate Thickness, In.	Specimen Number	Single Layer Welds: Yield Point, Lb./Sq. In.	Single Layer Welds: Ultimate Strength, Lb./Sq. In.	Two Layer Welds: Yield Point, Lb./Sq. In.	Two Layer Welds: Ultimate Strength, Lb./Sq. In.
	1	34,560	50,180	38,540	55,780
	2	35,670	52,200	39,560	58,640
1/4	3	33,250	50,180	41,780	59,780
	4	31,140	49,340	40,850	59,180
	5	30,240	49,180	42,780	60,140
	Average	32,970	50,220	40,700	58,710
	1	35,670	50,140	43,450	58,740
	2	37,680	52,250	44,560	59,640
3/8	3	40,720	53,340	41,850	57,450
	4	39,320	52,740	44,650	59,840
	5	41,240	54,850	45,820	60,160
	Average	38,930	52,660	44,070	59,170
	1	41,450	52,370	45,740	58,830
	2	44,560	55,680	42,380	55,750
	3	40,580	51,140	44,780	57,460
1/2	4	42,460	53,450	43,420	56,540
	5	43,720	54,850	46,780	61,230
	Average	42,550	53,500	44,620	57,960

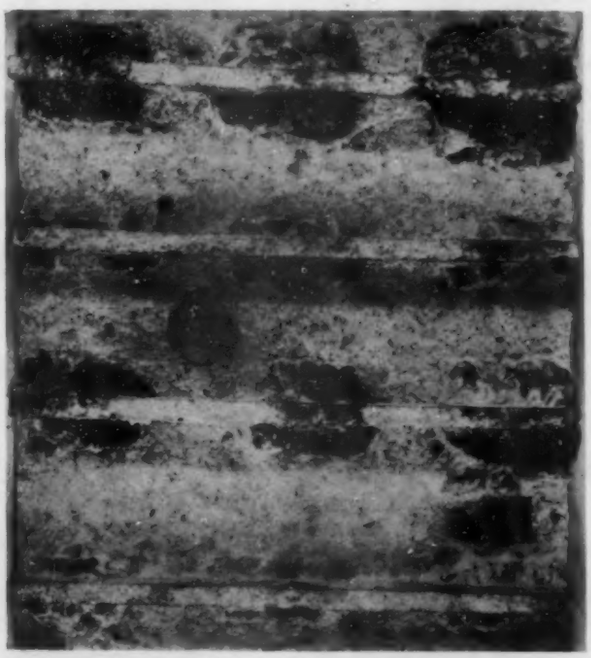


Fig. 14—Fillet-Welded Specimen after 1100 Hrs. in the Salt Spray

gives about the worst possible welding conditions because the zinc between the faying surfaces will also melt and fume into the weld.

The strength values given are those of the base metal outside of the joint, and not those of the weld metal. The value of these tests is, therefore, largely relative.

It will be seen that there is a loss in strength of some 8 to 15% when welds are deposited in one layer instead of two. It is possible that the greater strength of the latter is due to the fact that the two-layer welds were bigger than the single layer one; it would not be at all difficult to vary the size to a greater extent than that in an unmachined weld.

The strength developed by the two-layer welds is about what might be expected from bare-wire deposits.

In view of the above it seems reasonable that there is a slight loss in strength in single layer welds on galvanized material, but very little loss in multiple layer fillets. If desired, the requirement could be enforced that all welds on galvanized material be made with multiple beads, but such welds are not as well protected against corrosion as are single bead fillets. In view of the fact that large factors of safety are used in welded design, it would seem better practice to accept a slight loss in strength to obtain better resistance to corrosion.

7. Effect of Welding on Health of Welders

In naval ship construction there is a great deal of welding that must be done down in inner bottoms and closed structural tanks of various kinds. Ordinary welding is often uncomfortable enough under these circumstances, but the welding in these spaces when galvanized presents a very serious problem. Welders breathing the zinc or zinc oxide fumes for relatively short periods contract what has been called "welders' ague."

The best preventive devices are none too good; the ventilation of the compartment should be adequate, that is, large quantities of fresh air should be forced in continuously; the welder's face and eyes should be protected from the fumes by gas masks of various kinds. All protective devices are, however, hot and disagreeable to wear and the temptation to dispense with them is great. In spite of all efforts along the lines mentioned, the welding of galvanized steel, particularly in closed compartments, is still fraught with trouble.

8. Summary

(*a*) In plating 1/2 in. thick and thicker, normal welding on one side will not burn off the galvanizing on the other side.

(*b*) The corrosion resistance of plating from which the galvanizing has been apparently burned off by the heat of welding, does not seem to have been lessened in any great degree.

(*c*) The zinc coating is completely burned off only along a very narrow zone at the toe of the weld; the zinc is melted at a considerable distance from the weld, but the protection of this melted zone is not impaired.

(*d*) Covered electrodes burn off the zinc to a greater extent and to a greater distance from the weld than do bare electrodes, but only to a small degree.

(*e*) Multiple bead welds burn off the zinc to a greater extent than do single bead welds, but only to a small degree.

(*f*) Galvanizing increases the porosity of the single bead deposits somewhat, but not to as great a degree as might be expected. The increase in porosity is negligible in multiple bead welds.

(*g*) Galvanizing decreases the strength of single bead deposits a small amount; the strength of multiple bead deposits seems to be little harmed.

(*h*) There seems to be little difference in the corrosion resistance of bare and covered electrode welds.

(*i*) Small single bead fillets seem to have practically as much resistance to corrosion as the original galvanized plate. Large multiple bead welds, however, are attacked readily.

In view of the above it appears that the effect of the welding on the galvanizing can be considered negligible, that the effect of the galvanizing on the welding is of little practical importance, but that the real problem in the welding of galvanized steel is the protection of the health of the welders.

Development and Application of Automatic Welding Controls

By H. W. ROTH

✦Paper presented at Fall Meeting, A. W. S., Detroit, Oct. 2nd to 6th, by H. W. Roth, President, Controloweld, Inc.

Introduction

TEN years ago, the welding engineer who tried to preach the use of automatic controls for spot welding, the use of high voltage and short welding time or the use of synchronous controls for spot and seam welding did not find many followers even among the experts of his own trade. Today, an ever-increasing number of engineers and production men are convinced that the days of old-time welding are gone and that for production purposes the use of automatic welding controls is an indispensable necessity.

There is, however, a certain want of clearness as to the proper way of using welding controls for the individual job.

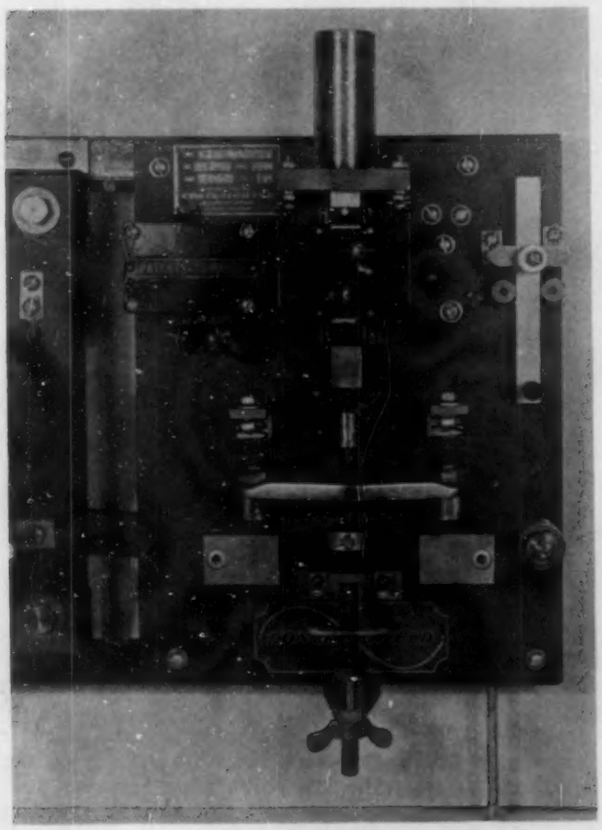


Fig. 1—Controloweld Time—Differential Relay

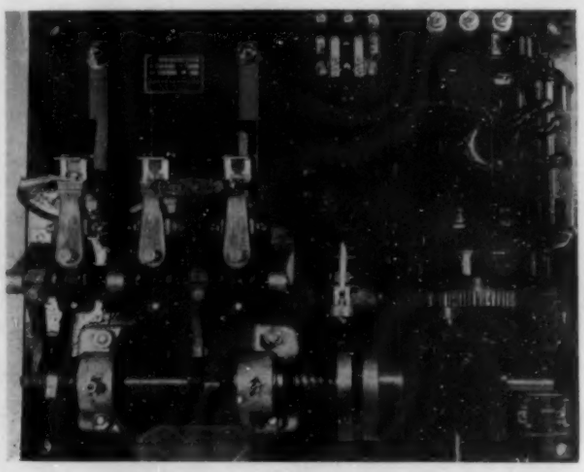


Fig. 2—Synchro-Spot-Welding Control

Why Automatic Controls?

Generally, the purpose of automatic welding controls, especially in spot welding, is to provide means for automatically disconnecting the welding current exactly at the moment when the proper welding heat has developed. Greater uniformity and dependability in spot welding, greater economy with regard to the amount of power consumption and welding time, considerable saving in electrode material and, last but not least, less metal finishing wherever a clean and smooth appearance of the spot weld is required; these are the most important improvements introduced by automatic welding controls. In addition to this, automatic controls paved the way to new developments in spot welding, to the design of simple and better full-automatic spot-welding equipment, especially for high production applications.

History of Welding Controls

For a clearer understanding of the details it may be useful to sketch a few lines regarding the historical development of automatic controls for spot welding and seam welding. A sketch of this kind, however, will be far from being complete, and therefore any contribution or discussion from any side will be highly welcome.

The customary way of controlling the welding time has been the push-button control on hand-operated welders or the control by foot pedal on foot-operated welders. With both methods the result depends entirely upon the skill and the attention of the operator. The push-button control is superior to the ordinary foot-operated control as it presents the possibility of holding the electrode points under full pressure for a short while after the current is switched off. Then the surface of the metal is chilled and the weld is perfectly solid when the pressure is released. The ordinary foot-operated control opens the primary current only when the operator starts to release the pressure. Spot welds with large blue discoloration, frequently with burnt metal surface and poor ductility, are the result. An improved type of a foot-operated control is the so-called "trip-switch," which is used as a standard equipment by many modern welders. This switch opens the welding circuit when the foot pedal reaches its lowest point, in other words, under the maximum pressure. If this type of control is used in the proper way, it guarantees a very good weld, providing the operator is attentive enough to use uniform speed in operating the food pedal. In many plants, however, we can find spot welders equipped with this

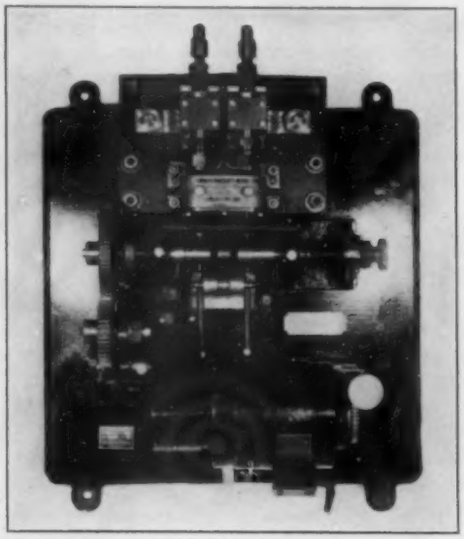


Fig. 3—Synchro-Seam-Interruptor

type of trip-switch, but either not adjusted in the proper way or only used as an ordinary switch. This lack of attention or knowledge is characteristic of so many cases and is mostly the cause of disappointment with the results of spot welding.

The earliest type of *full-automatic controls* has been used for many years in connection with automatic motor-driven spot welders and is already mentioned in an early American Patent, issued to Hugo Hellberger in 1907. It is a cam-operated switch working on a straight timing principle, as the length of an adjustable cam and the revolutionary speed of the cam shaft directly determine the welding time. The results obtained with this type of control are satisfactory as long as the welding speed does not exceed approximately 250 spots per minute and as long as no scaly or rust-spotted metal has to be welded. We will refer later on to the limitation in speed and now discuss the question of welding scaly metal, which is of a limited importance in body welding but, nevertheless, of great interest for many branches of the sheet metal industries.

Scale, as well as rust, is a non-conductor. Therefore, the comparatively low voltage of the secondary welding circuit mostly is not able to penetrate through the scale immediately after the welding circuit has been closed. Sometimes it takes a fraction of a second or even several seconds to start the welding current. In many cases a slight movement of the sheet metal between the welding points will help to remove the scale or rust and to start the weld. This time delay between the closing of the primary circuit and the actual start of the current in the secondary welding circuit makes it nearly impossible efficiently to use a straight timing control. The timing control may open the primary circuit before the weld has even started.

To meet this condition several special controls have been developed. The oldest type is the maximum control, patented in 1919 by Richard Mack. It is based on the following principle: In making a spot weld the welding current shows a slight increase at the moment of fusion between the sheets, due to the better and larger contact area. This increase in amperes, although it amounts only to between 5 and 15%, can be used to operate a maximum relay which, in turn, operates a magnetic switch to open the primary circuit. The applications of this principle, however, proved to be rather limited. First of all, the increase in amperes only takes place when the total welding time is long enough to allow a discrimination between the resistivity in the welding circuit at the start and at the finish of the weld. The shorter the total welding time, the less increase in current can be noticed at the end of the weld. Another difficulty is caused by the impact current. For using a short welding time and high welding current, the impact current may be higher than the final increase in amperage, thus operating the relay too early.

Striving to overcome these difficulties, the author in 1923 developed a spot-welding control, known as current-timing control. As the name illustrates, this control depends on time *and* current. A timing relay is inductively connected to the welding circuit, either to the primary or to the secondary coil, and thus the timing is automatically corrected by the welding current. A momentary increase in current will cause the timing relay to work faster; a decrease of welding current will slow it down. Practically, the device multiplies time by current. As this product—time by current—determines the amount of power supplied to the weld, the relay will practically control the welding heat and automatically correct the time according to the conditions.

Several hundreds of relays of this type have been in service since 1924 and have proved satisfactory for welding clean stock as well as scaly metal. The influence of the impact current is practically eliminated through the inductive coupling as well as through the time delay. To a certain extent, the time current relay will also take care of the variations in thickness of the metal to be welded, as thicker metal has higher resistance, and therefore the welding current will be smaller, which, in turn, automatically lengthens the welding time.

Another development along the line of spot-welding controls with automatic adjustment is the differential relay. Its basic principle is similar to the maximum relay, but with the improvement of self-adjustment through the introduction of a potential coil. Both the maximum coil, inductively connected to the welding current, and the potential coil, which is parallel to the secondary voltage, are balanced at the start of the weld. As soon as the weld takes place—regardless of the thickness of the metal—the increasing current and, at the same time, the drop in voltage throw the relay out of balance and operate the primary switch. This principle makes it possible to weld clean or scaly metal as well as galvanized iron, zinc, tin or lead-coated metal. But it

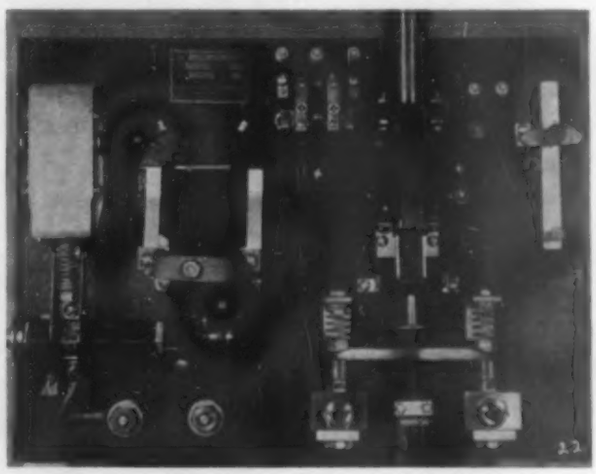


Fig. 4—Universal Control for Small Capacity

requires a rather careful first adjustment with regard to the individual machine.

An improved and simplified automatic control along this line is shown in Fig. 1. It is a combination of a differential and timing relay and incorporates the advantages of both, at the same time avoiding the limitations of a straight timing device or a straight differential relay. Either one can be used separately, or both in combination. The control, therefore, is universal to a certain extent. None of the welding controls on the market are, however, one-hundred per cent universal as yet. The devices which we have described above may be satisfactory for certain applications and under certain conditions, as pointed out, but other conditions called for different developments. To illustrate this we may refer again to spot welding of clean sheet metal.

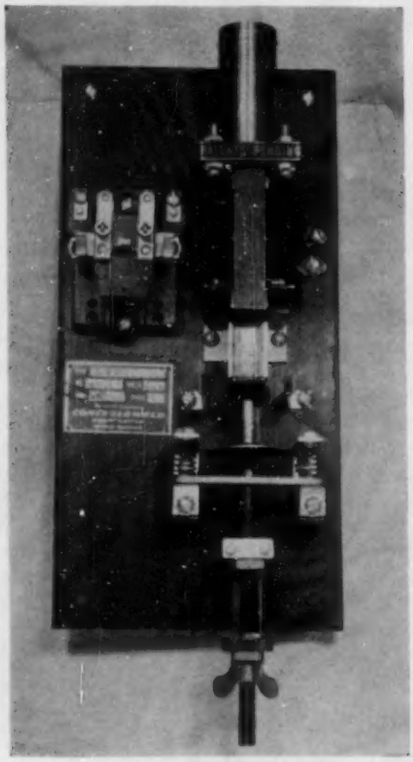


Fig. 5—Timing Relay

In 1921 we made a great number of experiments to find the most favorable conditions as to welding time, welding pressure, shape of welding points and amount of current for various thicknesses of metal. We found out very soon that we were able to produce a practically invisible weld by using extremely short welding time, high capacity welding transformers with high secondary voltage and rather high welding pressure. We tried to shorten the welding time more and more and now the problem of exactly controlling the welding time confronted us. We could not use a maximum relay on account of the conditions described above. We were compelled to use straight timing. But ordinary magnet switches would not do, as the time delay to close the switch was too long and too inexact. We, therefore, arranged two switches in series in the primary circuit. The first switch was normally open, the second switch normally closed and equipped with a fast-acting timing device. The first switch was used to start the weld and immediately afterward, with an extremely short time delay, the second switch opened the circuit and finished the weld. Welding as short as one cycle or less made completely invisible welds, as the welding heat was developed between the sheets and did not have sufficient time to spread to the surface of the metal, which, in addition, was cooled by the welding points. For the same reason, we obtained better results than ever before in welding brass, aluminum and other high conductivity metals or alloys. This process, which we called "instantaneous or momentary welding," seemed to be very satisfactory and a number of machines, equipped with this kind of controls, are still in production for high-finish metal products.

We noticed, however, that the results in welding were not quite uniform and, going more carefully into the matter, we found out—a well-known fact today—that the cycles of the welding current were to blame for the variations. When we closed our primary switch at the moment where the sine wave was on its high point, a heavier impact in the transformer would increase the amount of welding heat. Especially in welding high conductivity metal, this factor was important.

In 1923 the author applied for a patent, issued in 1924, on the idea of using a synchronous control for welding machines to overcome these difficulties.* Today, synchronous controls, either of the mechanical type or the tube type, are used wherever an exact amount of energy has to be supplied to the weld. This is done in spot welding stainless steel, aluminum brass, etc., and also in welding steel under certain conditions. In Fig. 2 a mechanical type of a synchronous spot-welding control is shown. A synchronous motor drives a cam shaft through an automatic clutch, which is controlled by press button or other means. Three contacts are provided and operated by two individual cams. One contact is normally open, two are normally closed. When the clutch is engaged, the one cam will close the left contact and start the weld, while the second cam, after a certain time, opens the double contact to finish the weld. Thus, the welding time can be made extremely short, from six cycles to one-half cycle. The motor is adjustable to place the break point into the neutral line of the sine wave to avoid arcing. Forced by the ever-increasing use of stainless steels since 1926, we developed a similar control for seam welding. Wherever seam welding with interrupted current has been used, the old-style mechanical interruptor caused most severe difficulties through excessive arcing and through lack of uniformity in welding. The synchronous interruptor brought about an important improvement. While several years ago it was claimed to be impossible to build a synchronous mechanical interruptor for practical application, we are able today to control 500 amperes with a speed of 15 interruptions per second without difficulties.

Figure 3 shows a control of this type. The heavy copper contacts are water cooled and open $^1/_{32}$ in. only. The zero adjustment is completed in a very simple way, by turning the motor field.

The adjustable cam of this interruptor allows placing the "make" of the primary current into any point of the sine wave, while the "break" occurs practically in zero. This double adjustment makes it possible to select the most favorable induction curve for the individual job and the individual machine.

Parallel with the development of synchronous mechanical controls, several types of tube controls have

* We call a synchronous welding control any type of control which supplies a predetermined number of cycles or part of a cycle to the welding transformer, working in synchronism with the sine wave of the welding current. The practical development of this type of control, however, took several years.

been developed, with regard to which we refer to papers to be presented later on.

Conclusion

Overlooking the general field of spot welding and seam welding, the following conclusions may be drawn as to the application of welding controls:

Ordinary Production Spot Welders

1. Welding clean sheet metal of uniform thickness: a straight timing device is satisfactory. (As Fig. 1 in connection with foot-operated machines without magnet switch, or as Fig. 5 in connection with magnet switches.)
2. Welding clean sheet metal with variations in thickness: a time current relay or a differential timing relay may be used in connection with a magnet switch. For a foot-operated welder without magnet switch, a universal type as shown in Fig. 4 is applicable.
3. Welding scaly material: a time current control or differential timing control is necessary.
4. Momentary welding.—On *small capacity* foot-operated welders, a normally closed control as Fig. 1 may be used in connection with a normally open foot-pedal switch. On portable welders and high capacity welders (above 25 kva.), a synchronous control is necessary. Momentary welding should be used wherever invisible welds or welds of high finish are required, providing the capacity of the welding machine is large enough to use extremely short welding time. Furthermore, in welding stainless steel, aluminum and alloys, a momentary weld is necessary. In connection with portable welders, a momentary weld is useful to avoid heating of the cables.

A general rule is this: Wherever the conditions allow it, use the shortest possible welding time to save metal finish, electrode material, current and time. But study the conditions before you decide which control to use. There is no ideal control on the market as yet, which would do everything under any condition. Even the best welding control will not be able to correct fundamental mistakes with regard to the welding conditions. But wherever the right type of a welding machine is used, where the welding points are properly designed and made out of the right material and where the parts to be welded are in the right shape, a modern automatic welding control certainly will guarantee a uniform and satisfactory weld.

Timing of Spot Welders with Respect to Current Flow

By **D. C. WRIGHT**

✦Paper was presented at Fall Meeting, American Welding Society, Detroit, Oct. 2nd to 6th, by D. C. Wright, Chief Engineer, The Electric Controller & Mfg. Co.

IT IS a well-known fact that, in order to secure uniform and perfect welds when spot welding any material, it is necessary to have *uniform* temperature as well as proper temperature between the pieces welded. The welding temperature is produced by the B. t. u. put in the pieces between the electrodes.

All electric circuits generate heat which can be expressed by the formula:

$H = KI^2RT$ where

H = total heat units in B. t. u.
K = a constant
I = value of current in amperes
R = resistance of the circuit in ohms
T = time of current flow

When this formula is applied to the circuit between the electrodes of a spot welder, it seems apparent that the B. t. u. varies directly with the time, directly with the resistance and directly with the square of the current. However, I varies inversely with the resistance in an electric circuit, therefore, the B. t. u. vary directly with the current and time. This can be proved by the following example: assume

I = 5000 amperes
R = 0.05 ohms
T = 1 sec.

Then $H = K \times 5000^2 \times 0.05 \times 1 = K \times 12{,}500$

Now assume the resistance has, for some reason, increased 10%; then the current will have decreased 10%, and in order to get the same B. t. u. we must increase the time 10% or

$$H = K \times \left(\frac{5000}{1.10}\right)^2 \times (0.05 \times 1.10) \times (1 \times 1.10)$$

$$= K \times \frac{5000^2}{1.10^2} \times 0.05 \times 1 \times 1.10^2 = K \times 12{,}500.$$

It is thus seen that in order to keep the B. t. u. constant, it is necessary to keep the product of current and time constant.

The resistance between the electrodes of a spot welder includes the contact resistance between the electrodes and the material, the electrical resistance of the pieces and the contact resistance between the pieces or plates themselves. The majority of spot welding is done on steel. The electrical resistance of steel is many times that of copper. The contact resistance of steel to steel is, therefore, much higher than of copper to steel and is higher than the resistance in the plates themselves; therefore, the most intense heat is generated between the plates, rather than in the plates or between plate and electrode. This is a fortunate condition as it puts the heat at the point desired and gives a relatively small amount of surface heat and consequent discoloration.

If the electrical resistance between the electrodes was always the same on given pieces of material, we could expect all welds to be perfect, if made on a given tap at fixed voltage and at fixed time. But, unfortunately, there are many variables in the resistance of the circuit

Fig. 1—Top and Bottom Views of Laminated Section of 2–6 Thicknesses, Inclusive, Welded without Change in Adjustment

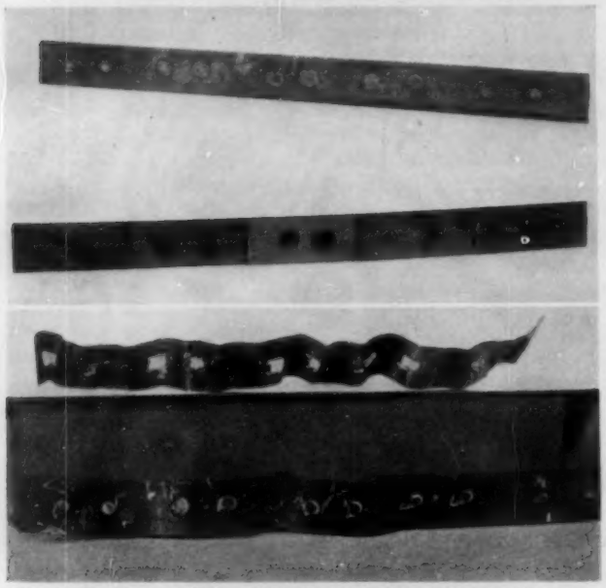


Fig. 2—The Bottom Strip of Laminated Section Removed, Showing a Perfect Weld at Each Point

which affect the current flow and consequently the welds produced. The contact resistance of the metal may vary over a wide range due to condition of the surface; a bright, clean surface will have lower contact resistance and pass more current than steel oxidized to any extent, tarnished or showing scale or rust. Changes in line voltage affect the voltage at the welder points. A drop in line voltage will require an increase in welding time to get the same uniform results. Line voltage is likely to vary over a wide range in a plant where a number of welders are connected to the same circuit.

Condition of the electrode points will also affect the value of the welding current. After the points are dressed to a bright, clean surface, repeated use will oxidize the surface; pitting and roughening also occur with the result that the electrode points offer greater resistance to the flow of current, making it necessary to pass current for a longer time to get the same uniformity of welding.

Variations in pressure on the electrodes cause variation in contact resistance between electrodes, material and between the pieces of material. Too much pressure may reduce the contact resistance between the pieces to such a low amount that there will not be enough heat developed at this point to weld. Too light a pressure may cause burning and arcing at this point with resultant gas pockets formed.

Variations in the thickness of the metal being welded, or an increase in the number of pieces of metal, introduces another variable by increasing the resistance to the flow of welding current, and also by increasing the mass of metal available for carrying heat away from the welding zone. It is, therefore, evident that increasing the thickness of metal between the electrode either by increasing the gage of metal or increasing the number of pieces, will require either an increase in welding current, if the operation is to be performed in the same time, or an increase in time if current settings are not disturbed.

Present-day practice, as developed in high production plants, has speeded up spot welding operations by increasing the current and reducing the time so that 60 to 90 or more welds per minute are not at all unusual. It is evident that with this speed of operation, the length of time the current is actually flowing is of short duration. It is difficult for an operator to maintain anything like accuracy of welding time when he is dealing in fractions of a second; a variation of a small part of a second may result in double the quantity of heat. Manually controlled machines are fatiguing on the operator, with the result that at the end of the day's run, uniformity of welding time is likely to suffer.

To overcome those variable conditions, our Automatic Weld Timer has recently been developed. This device is for use on spot welders, projection welders and butt welders. It does not give constant time, but automatically adjusts the welding time to compensate for all these varying conditions described above, and properly proportions the time to suit the exact requirements for each weld that is made. Constant or definite time cannot be depended upon to give constant results under varying voltage or resistance conditions, and results either in too many B. t. u. or in not enough. Too many heat units give burned welds with bad indented and colored surface; not enough units give weak welds likely to pull apart. Burned welds require frequent dressing of the electrodes and consequent loss of time and production. Weak welds require more to be placed to give proper factor of safety.

With automatic control of time with respect to current, bright cold-rolled steel or black hot-rolled steel can be welded with equal facility. Variations in thicknesses, either in gage or in number of pieces up to considerable limits, require no change in adjustments. Oxidization or burning of electrodes, even to bad condition, is compensated for by allowing more time.

Figure 1 shows two, three, four, five and six strips of black hot-rolled steel welded with the same tap setting and without change in time adjustment. The time automatically increased with the increase of thicknesses to give perfect welds, as shown in Fig. 2.

Figure 3 shows a requirement in automobile body work, where the resistance between the electrodes varies to a considerable extent when welding the total length of seam *A*. Automatic Weld Timers are giving perfect welds without bad surface indentation under this varying resistance condition without change of adjustment.

Figure 4 shows another condition in body work where either two or three pieces must be perfectly welded without taking time to change the time adjustment to accommodate for change in thickness.

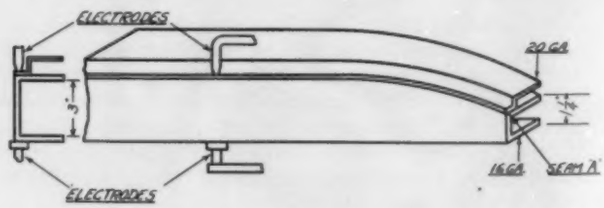


FIG. 3
WELDING THROUGH VARYING THICKNESS

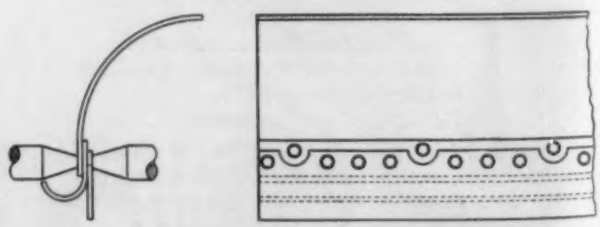


FIG. 4
WELDING THROUGH DIFFERENT NUMBER OF THICKNESSES.

In another case it is necessary to weld to a $^1/_{16}$-in. sheet, a piece of $^1/_{16}$-in. and a piece of $^1/_8$-in. steel. This was done by two operators on two different welding machines so as to save the time required for changing the time setting alternately for each piece. The work can be done with a single welder and an automatic timer without the operator being really conscious of the change of thickness of metal. This would save a considerable amount of time in handling the parts.

The means used in the Automatic Weld Timer to secure time with respect to correct flow are simple and yet positive in action. They are subjected to very little deterioration or wear and should give extremely long life. They include a small current transformer, a simple double-wave rectifier tube, a condenser, an adjustable resistor, two Neon glow tubes and two small relays. The transformer is connected in series with the primary of the welder. The secondary of the series transformer supplies A.C. voltage for the rectifier. The rectifier supplies D.C. voltage to the condenser in proportion to the A.C. current flowing in the welder. When the charge to the condenser has received a predetermined voltage, it discharges through the Neon tubes in series with the coil of one of the relays, causing this relay to operate the second relay, which, in turn, opens the welder contractor.

The dwell time of the welder contactor is, thus, proportional to the time taken to charge the condenser. This time is inversely proportional to the voltage applied for charging, which is a direct function of the current flowing through the weld. If the welding current is low, the time is long; or if the current is high, the time is short. The transformer is so designed as to keep the product of current and time practically constant throughout the whole range of operation. It is advisable, however, on low currents to make the time slightly longer than the true ratio, so as to compensate for conduction of heat away from the desired spot. This can be taken care of by proper transformer design.

The small adjustable rheostat is connected in series with the condenser. Its setting depends upon the character of the work being done, upon the welder transformer tap chosen, upon the general thickness of material and upon the alloy of the material being welded. In order to insure the proper time setting of the rheostat, a few sample welds should first be made to determine the proper tap setting of the welder and the proper time setting for the work at hand. After these have been determined by careful examination and tearing apart of the welds, the tap and time setting can be left alone, even though large variations, such as have previously been mentioned, occur in the character of material or in the resistance of the circuit.

The Automatic Weld Timer is shown in Fig. 5. All the parts, with the exception of the condenser, are mounted on the front of the panel. The cabinet is small and dust-proof and can be mounted on the welder or adjacent to the welder contractor.

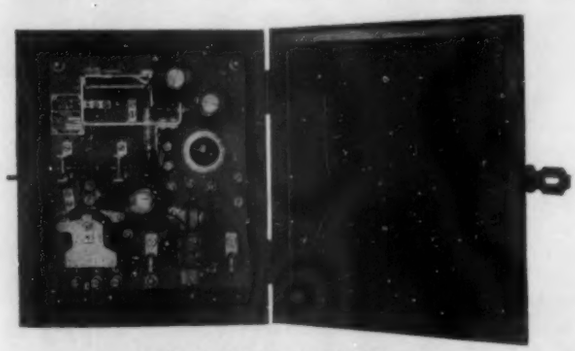


Fig. 5—Automatic Weld Timer

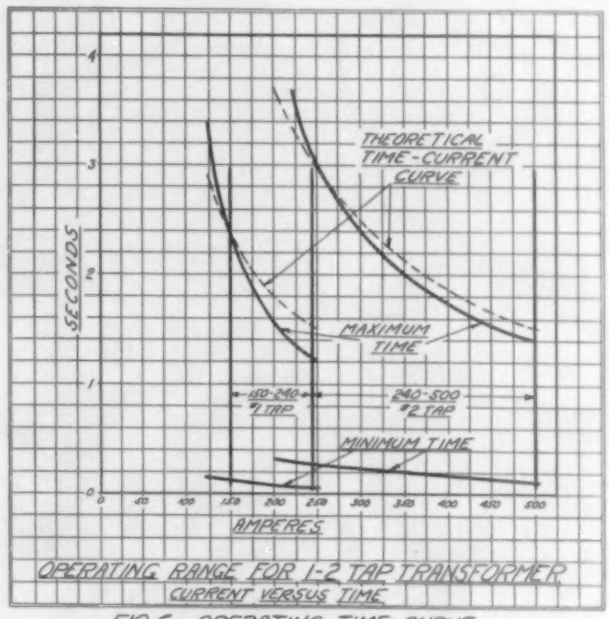


FIG. 6 OPERATING-TIME CURVE

The timer uses a normally open-type push button, which is not furnished with the timer, but usually is a part of the welder. The scheme of connection makes it impossible for the welder to repeat except by repeated operations of the push button.

The timer can be applied to manually operated, air-operated or hydraulically operated welders, where the timing is usually left up to the operator's judgment. The air or hydraulic valves can be replaced by solenoid valves, making it impossible for the operator to stop the weld until the timer has given proper time for opening of the contractor and release of the electrodes. The timer can be applied to motor-driven welders, where the time is determined by the length of a cam contact. This cam contact can be used to start the Automatic Weld Timer, and lengthened so as to open only after the timer has operated. On comparatively light work with a small, fast welder contactor, up to 140 welds per minute can be obtained—each weld properly timed with respect to current flow.

Since the transformer used in the timer is of the series type, its winding must bear some relation to the kv-a. rating of the welder. The transformers cover a considerable range, only four sizes being necessary to cover a primary current range of 25–500 amperes. Windings for smaller primary currents, even down to 5 amperes or less, are available, and for larger currents extra taps or extra series transformers for proper reduction of current can be used.

Most welders operate on relatively short time and it has been found that a single size of condenser will cover most all of ordinary spot welding conditions. This size of condenser gives approximately 2 seconds maximum and 0.1 second minimum time. By doubling the capacity, the times are approximately doubled.

Figure 6 shows a graph of time adjustment that can be obtained from one transformer having a current range of 150 to 500 amperes primary current. The maximum time at 150 amperes with all the rheostats in, is 2.4 seconds. The minimum time is 0.12 seconds. Any time between these limits or between the maximum time curves and the minimum time curves shown on the graph can be secured by adjustment of the small rheostat.

Fig. 7—Oscillograph Showing Change in Time When Welding Same Thickness of Material on Different Welder Taps

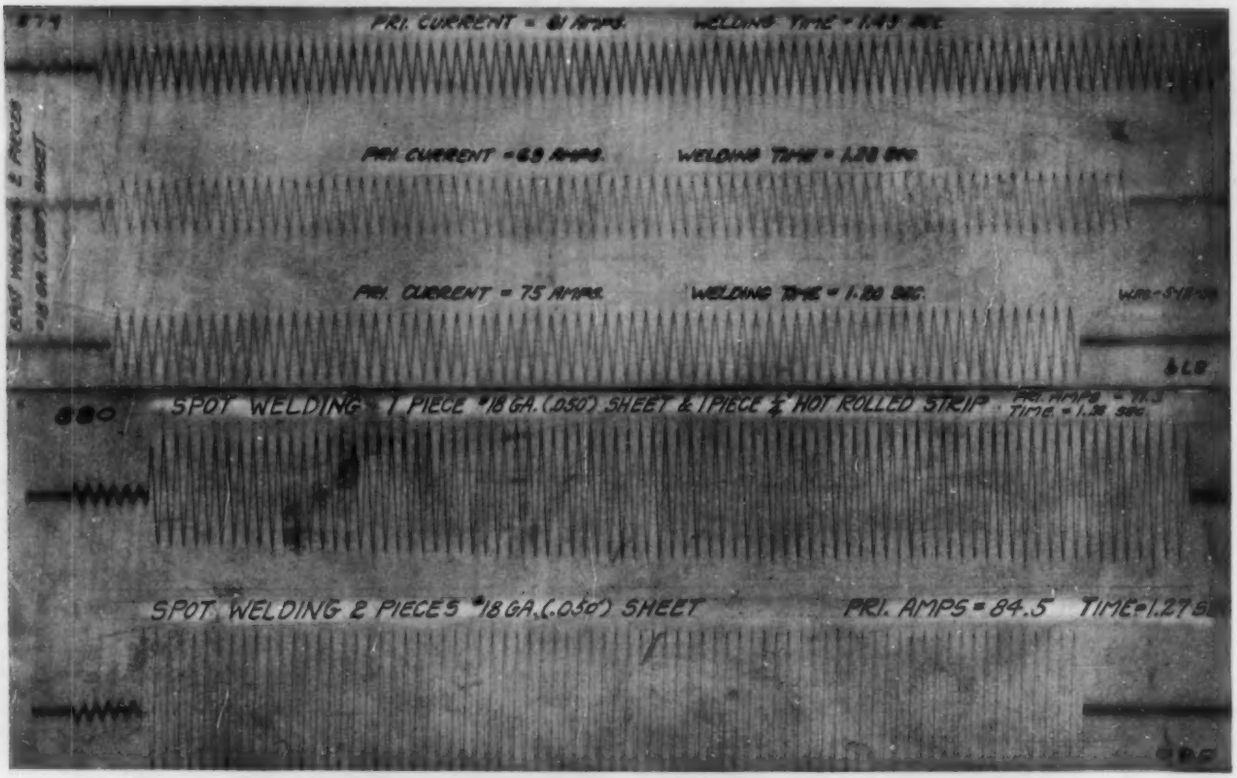

PRI. CURRENT = 69 AMPS. WELDING TIME = 1.43 SEC.
PRI. CURRENT = 69 AMPS. WELDING TIME = 1.33 SEC.
PRI. CURRENT = 75 AMPS. WELDING TIME = 1.20 SEC.
SPOT WELDING 1 PIECE #18 GA. (.050) SHEET & 1 PIECE ¼" HOT ROLLED STRIP
SPOT WELDING 2 PIECES #18 GA. (.050) SHEET PRI. AMPS = 84.5 TIME = 1.27 S

Fig. 8—Oscillograph Showing Change in Time When Welding Varying Thicknesses of Material

If the current exceeds 240 amperes, the secondary connections on the small transformer are changed to the No. 2 tap to secure the operating ranges shown by the curves to the right.

Figure 7 shows curves taken by an oscillograph to show the change in time which occurs when welding the same kind of material on different welder transformer taps. The time automatically decreases for higher taps used. Any of these taps shown gives proper welding. The time setting of the rheostat was left fixed.

Figure 8 is an oscillograph showing effect when welding different classes of material on the same welder transformer tap with the time setting left fixed. The time automatically shortened itself when welding the thin material to give good welds without burning, although the time had been set for welding the thin material to the $^1/_4$-in. plate.

Welding of stainless steel or aluminum is practically impossible where the control of the time and pressure is left up to the judgment of the operator. Stainless steel, having 8 to 12 times the electric resistance of ordinary steel, requires much less current to heat than ordinary steel. However, the outside surfaces must not be heated too much as carbide precipitates occur at high heat which destroys the stainless qualities. The time must be relatively short to prevent travel of the heat from the inside surfaces, where most of it is generated to the outside surfaces. These latter surfaces must not get red hot and, therefore, the operator has no visual indication as to when to turn off the heat. Contact pressure changes the contact resistance between the plates, even though the surfaces are bright and clean. Variations in voltage and electrode condition cause variation in current. Proper control of time with respect to current, independent of the operator, applies the same or more so here, as for ordinary steel.

Aluminum has very low resistance compared to steel and, therefore, requires a relatively high amount of current to generate the proper welding heat units. In order to properly weld the aluminum, plates have to be melted at the point of contact and yet not softened too much at the outside or else the electrodes will imbed themselves. The time has to be relatively short to prevent conduction of heat to the surface. Melted aluminum shows no distinct color. The operator has no visual means to show when to open the circuit. For these reasons the time must be accurately controlled, independent of the operator, but dependent upon voltage, resistance and pressure variations.

A summary of the advantages of controlled time are:

1. An inexperienced operator, after the time has once been fixed by the superintendent, can always secure good welds.
2. Since each weld has been properly timed, fewer welds are necessary for the required strength. This cuts down production costs and insures a more dependable product.
3. There will be fewer rejections and reduction in inspection costs.
4. Surface finishing costs can be reduced because of fewer surface burns or indentations.
5. High speed with accuracy can be obtained. On high speed work a fraction of a second in time may mean double the quantity of heat units put in the weld.
6. The fatiguing strains on the operator of manually controlled welders are reduced and the resulting inaccuracies are eliminated.
7. Dressing of electrodes is less frequent.
8. Elconite electrodes can be used to better advantage. The number of welds without dressing with this material is many times those secured from copper tips, provided they are not overheated by improperly controlled timing. When overheated, they require dressing with consequent loss of the expensive material.

COMMUNICATIONS

Discussion of Paper on "The Magnetic Characteristics of Deposited Metal"

By DR. W. E. RUDER

✦The paper on "The Magnetic Characteristics of Deposited Metal" was presented by Prof. Wendell F. Hess, D.Eng., Rensselaer Polytechnic Institute, at the Fall Meeting of the A. W. S., Detroit, October 2 to 6, 1933, and was published in the October issue of the Journal of the A. W. S. Dr. Ruder is connected with the General Electric Company, Magnetic Section, Research Laboratory.

AS FAR as I know, the investigation which you have made is the first of its kind which has been published. We have made some similar tests in this laboratory, but nothing nearly as exhaustive as you have undertaken, mainly because we see no direct application for the information at present. When welds are used in magnetic structures, it is usually possible to put them where they will do little harm, even if they were very poor magnetically. It is common practice with some manufacturers to weld sheets end to end to aid in the punching and fabrication. In such cases, however, the weld area of the sheets that are apt to get into any particular piece of apparatus is so small as to be negligible. In the case of these thin sheets butt or line welding is always used.

The results of magnetic tests are about what are to be expected. Magnetic properties are very sensitive to impurities, such as oxygen and nitrogen, and also to annealing treatment. The lower temperature anneal would do little more than relieve some of the strains which are set up by the rapid cooling in contact with the base metal. A true anneal, that is, above the AC_3 or upper critical point, would be necessary to segregate impurities, increase grain size and give the maximum benefit short of using a purifying anneal as in a hydrogen atmosphere.

I do not believe it is correct to refer to your treatment in hydrogen as "hydrogenizing." The improvement due to annealing pure iron or silicon-iron alloys in hydrogen has been known for years and is a little different from the process which Cioffi discussed in some of his recent papers and which he refers to as "hydrogenizing." He believed that he had produced a different material by treatment in hydrogen at a temperature very close to the melting point, that is, around 1400–1450° C. Some of us who have worked with hydrogen over a period of years feel it quite certain that all he really accomplished was an increased purification due to the very high temperature which he used. In addition, the use of a little water vapor in the hydrogen adds to its efficiency in decarburizing with unalloyed iron but is apt to be quite harmful when metals, such as silicon and aluminum, having difficultly reducible oxides, are present.

While hydrogen annealing the low impurity iron deposits, as well as those containing silicon, gives very much lower hysteresis losses and higher maximum permeability than those not so treated, these values are still from six to ten times the losses which have been obtained from iron or silicon-iron alloys which have not come through the arc.

The paper makes available to the engineer a lot of data which would ordinarily be difficult to obtain and which should be a definite guide to any who are considering the use of an appreciable weld section in a magnetic circuit.

Precision Spot Welding with Tube-Controlled Contactors

By CARROLL STANSBURY

✦Paper was presented at Fall Meeting, American Welding Society, Detroit, Oct. 2nd to 6th, by Carroll Stansbury, Research Engineer, Cutler-Hammer, Inc.

PROBABLY the most important form of resistance welding machine, considering its very widespread use, is the ordinary spot welder. Forms of this machine have been made for a great many years and there are understood to be upward of 100,000 of such machines installed, a fair percentage of which are doubtless in use at the present time. In its simplest form it involves merely a transformer, a pair of electrodes arranged to be pressed together on the work by foot or hand levers and some form of electrical switch for commutating the current in the primary winding of the transformer. More elaborate forms include power operation of the electrode (by motor drive or hydraulic or air pressure), a magnetically operated contactor taking the place of the manually operated switch and, particularly in the motor-driven units, some form of automatic control of the duration of the weld.

In spite of the early recognition of the desirability of automatically timing the weld, with its obvious advantages, probably the large majority of such machines in use today do not include such controls. Where the machine is motor driven as regards the movement of the electrode, the addition of such timing is a simple matter and has been very commonly used, but with the foot- and hand-operated machines and also on hydraulic and air machines, no such simple and relatively satisfactory solution has until recently been available. This has been particularly true in the case of portable spot welding machines such as the so-called gun welders of both the hand- and pneumatically-operated types in use on automobile body work.

The need for a really suitable automatic timer has been accentuated within the past few years by the growing recognition of the production economies and improved

output made possible by the use of higher welding currents and shorter time. This tendency has made manual control even less satisfactory than formerly, so that some form of automatic control has become practically obligatory.

A variety of devices have been tried out in the past in an attempt to meet this need. Dashpots have been quite widely experimented with for this service but have not proved satisfactory. Current- or voltage-responsive relays depending on changes in the current or voltage values associated with the welds, or a combination of the two, appear to have only a limited applicability, being limited to those classes of work where the percentage change of these quantities can be counted on to be of sufficient magnitude to insure positive operation. Motor-driven timers, particularly of the synchronous type, appear to be reasonably successful but they are expensive, require considerable maintenance, are somewhat inconvenient to adjust, and are, therefore, not applicable to the great bulk of spot welders in service.

Within the past four years two different forms of electrical timing have been applied to this problem with a success which seems to indicate that such timers are destined to dominate this field of control in the future. These two fundamental forms of electrical timing embrace:

1. Timers based on the time of building up or decay of magnetic flux in an iron core (electromagnetic).
2. Timers based on the time of building up or decay of electric charge in a condenser (electrostatic).

The writer and his associates have successfully applied both of the above principles to welding problems, but, generally speaking, have found the electrostatic method preferable because it lends itself to simpler apparatus which is more flexible in application, permits a much wider variation in timing and does not require delicate magnetic relays requiring expert adjustment. Moreover, the electrostatic method is adaptable to the development of timers having a synchronous characteristic as brought out later in this paper.

The original electrostatic timer in its simplest form for spot welding is shown in Fig. 1. It consists of a single thermionic tube of either vacuum or gaseous type, a condenser *C* which is normally kept charged to a definite value between timing operations, and adjustable resistor *R* through which the charge on the condenser discharges during a timing period. The pilot device is shown as a normally closed push-button, for which, of course, may be substituted a limit switch actuated by the movement of the mechanical linkage associated with the welding electrodes.

In operation between timing periods the tube is conductive so that the magnetic relay *CR* is kept energized, holding open its contacts and keeping the welding contactor de-energized. Operating the pilot switch results in de-energizing the coil of the *CR* relay, due to the resulting blocking action of the charge on condenser *C* on the tube, so that the contacts of relay *CR* close, energizing the welding contactor for a timing period depending on the time of dissipation of the charge on *C* through adjustable resistor *R*.

Various improvements and refinements of this simple unit have followed, culminating in the commercial device shown in Fig. 2, a considerable number of which are in very successful commercial operation. This unit includes a grid-controlled mercury vapor tube. The transformer in the upper right-hand corner of the assembly supplies filament voltage to this tube and includes separate secondary windings for various other purposes involved in the control. The magnetic relay shown to the left of the tube has a set of main contacts for commutating the current of the welding contactor and a set of auxiliary contacts which function in the grid circuit of the tube. Below the magnetic relay is mounted the timing rheostat in front of which is a dial, which is arbitrarily calibrated from zero to 100 and has stamped thereon the approximate maximum and minimum time available with the particular rheostat used. Back of the rheostat and dial plate is mounted the timing condenser.

The typical circuit involved in the application of this device to a welder is shown in Fig. 3. It is merely necessary to connect the welding contactor coil in series with the terminals 1–2 on the timer, connect the pilot device to terminals 3–4 and run in a pair of supply lines L^1–L^2 for energizing the timer. These latter lines preferably come from a lighting circuit to avoid the severe voltage fluctuations commonly encountered on power lines supplying a number of resistance welding machines.

A development which is more recent than the timer of Fig. 2 is the somewhat simpler device shown in Fig. 4. This timer differs from that of Fig. 2 in that it uses an ordinary radio tube (type 50) in place of the more expensive gaseous tube. This form of timer as at present developed is not quite as accurate as the mercury timer and its timing range ($^1/_{30}$th to 2 seconds) is not as great as that available with the former. On the other hand, its accuracy and timing range are entirely adequate for the majority of spot welding applications and its advantages in simplicity and cheapness are obvious. The methods of application of this timer to a machine are the same as those followed with the gaseous tube timer of Fig. 2.

Some Typical Installations

Figure 5 shows schematically the method of application to an hydraulic or pneumatic welder. A welding operation is initiated by the operation of the valve in the air or fluid supply line. After the electrodes have come together and the proper pressure has built up, the pressure switch closes its contacts, initiating operation of the timer and closing the welding contactor for a definite period. This principle has been applied both to large stationary hydraulic machines and also to portable pneumatic welders.

Figure 6 shows a controller for a large hydraulic machine which very well exemplifies the flexibility of these methods of electric timing. In the center of the panel are three rheostat dials which may be independently adjusted. A weld is initiated by the operator by pressing one of three start buttons located at the welding electrodes. This gives the operator a choice of three different timing periods depending on the part of the work being welded. This controller also includes an electromagnetic timing arrangement which provides a definite period after the cutting off of the welding current before the hydraulic pressure is removed from the welding electrodes. This permits the welded material to solidify before the pressure is removed and is an essential feature in heavy work, particularly in projection welding.

Advantages of Automatic Timing of Welds

Although the advantages to be derived from accurate control of the types described above are fairly well known, it will probably be worth while to summarize them briefly at this point.

The assurance of all welds being uniform not only eliminates spoiled work but it has been found in a number of cases that it eliminates the additional expense of inspecting the work. There is also a saving in production

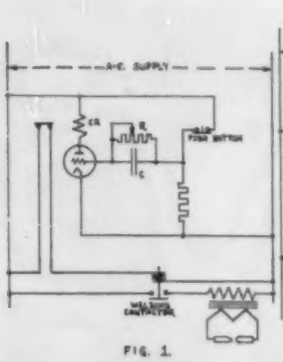


FIG. 1.

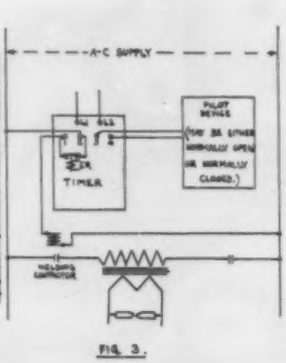


FIG. 3.

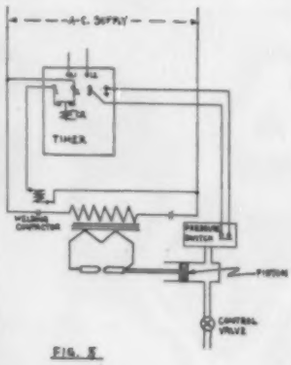


FIG. 5.

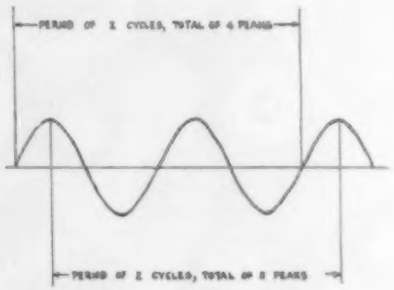


FIG. 7

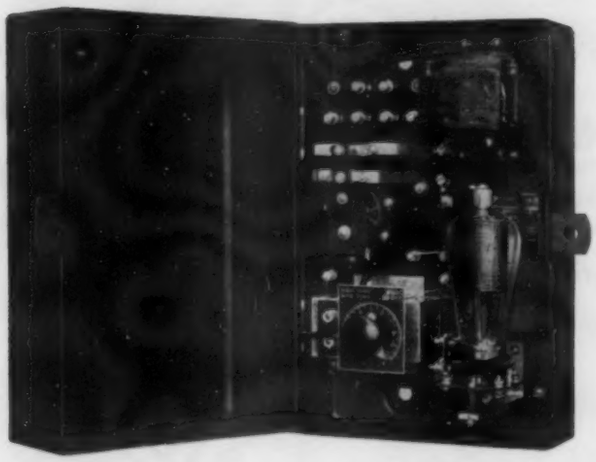


Fig. 2—Electronic Timer—Mercury Tube Type

time as only enough time is consumed on each welding operation to obtain a satisfactory weld. Uniform welds reduce the cost of finishing each piece and prevent the occurrence of pieces which have to be rejected. There is also a saving in the fact that it is not necessary to weld as many spots as is the case if automatic timing is not provided, and all the welds cannot be counted on as being good. Little or no skill on the part of the operator is necessary where the weld is automatically controlled.

In comparing the electronic timer with other types of automatic timer, it will be seen that the adjustment is much more convenient and can be recorded as a standard part of the set-up routine for a particular piece of work. The electronic timer has no moving or wearing parts except the small armature of the magnetic relay, which will operate without attention for many millions of operations and can ultimately be replaced at small expense. Similar remarks apply to the relay contacts, which are also ultimately easily and inexpensively replaced. Although the tube of an electronic timer must be replaced periodically, it has been the uniform experience that the cost of tube replacement is negligible in comparison with the production economies obtainable with the device. It should also be borne in mind that the inevitable course of development of tubes will be toward longer life and lower prices.

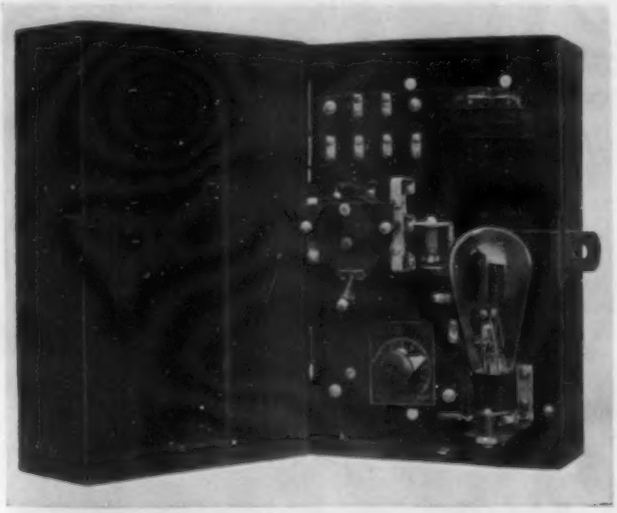


Fig. 4—Electronic Timer—Vacuum Tube Type

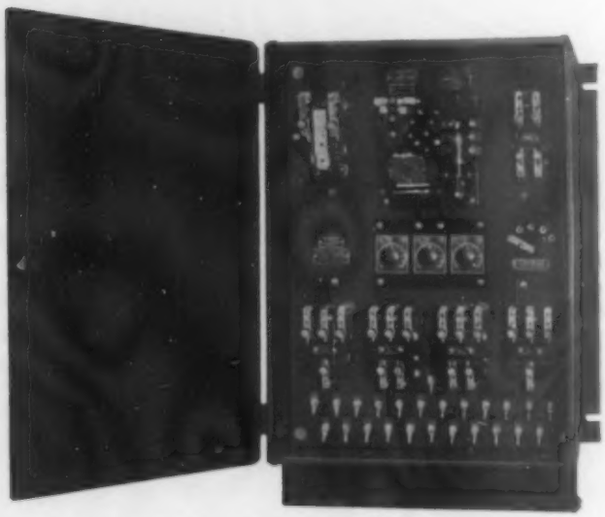


Fig. 6—Panel for Welding Controller

Methods of Checking Accuracy of Timing

As an introduction to the question of accuracy of spot welding control, it will be well to discuss at this point the methods available for determining the degree of accuracy existing in a given installation. The method most commonly used is by inspection or test of the resulting welds. Although, of course, such inspection says the last word with regard to whether the welding apparatus is satisfactory or not, it involves other variables than time and at best is only a sort of qualitative measure of the accuracy of the timer as such.

The best check, of course, is by the oscillograph, but this is somewhat cumbersome, expensive and not particularly well adapted to rapid checking up of the performance of a number of installations in different locations. Cycle counters of the ratcheting and other types have an error in themselves of at least $^1/_2$ cycle and more-

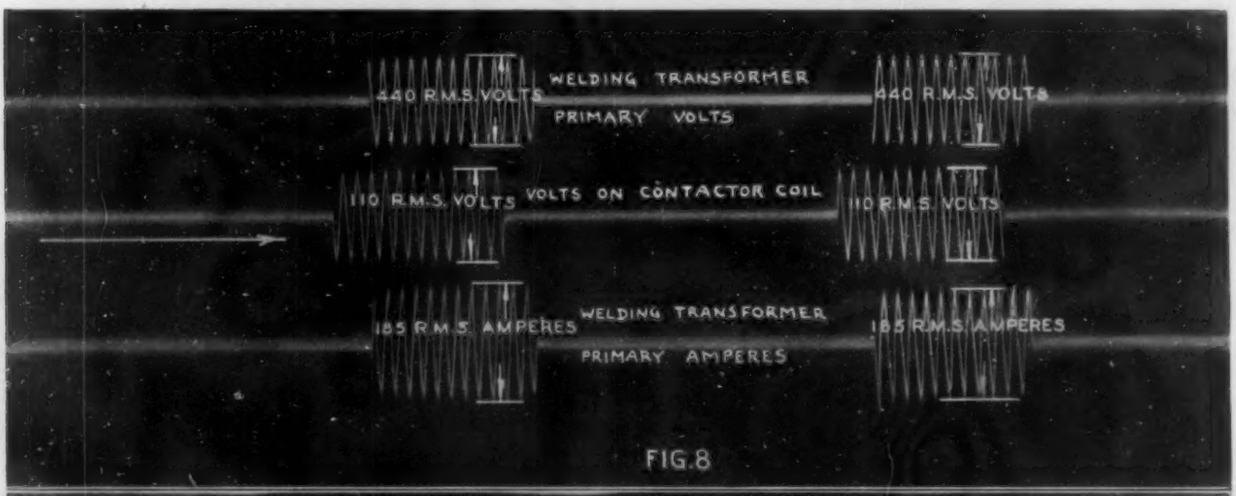


FIG. 8

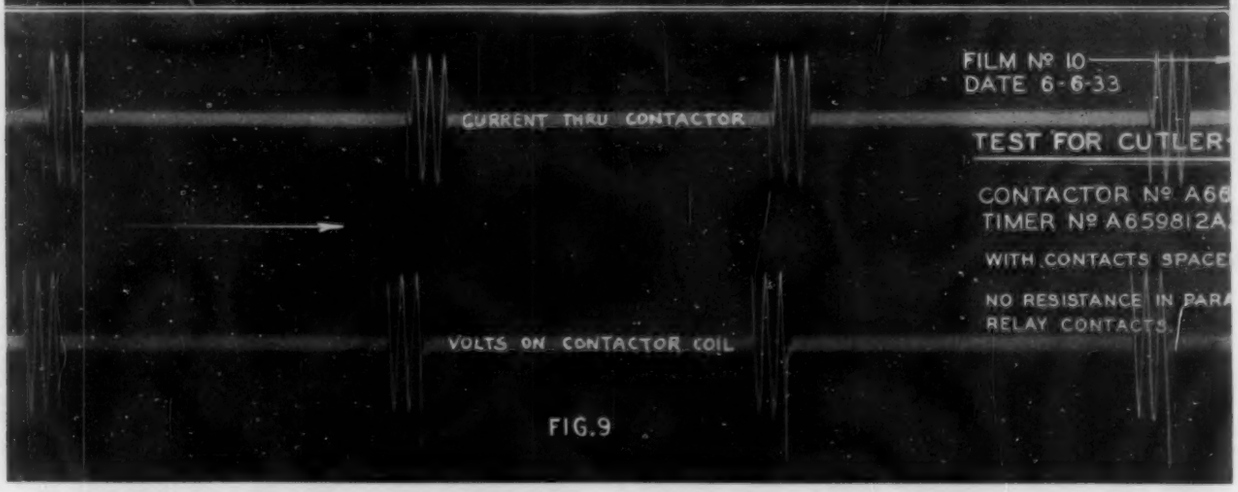


FIG. 9

over are not adapted to recording the time of a number of periods coming in rapid succession. Timing can be quite accurately checked with a ballistic galvanometer but this also is not adapted to checking timing periods coming in rapid succession, and also requires a separate auxiliary contact on the timer being checked to close the circuit to the galvanometer, the said contact not necessarily being closed for exactly the same period as the timer contact being checked.

We have, therefore, found that apart from occasional checks with the oscillograph where the expense is warranted, the most satisfactory checking means is a device which counts the half cycles by causing each voltage peak to puncture a moving sheet of treated paper. This device is made up in portable form and consists of a spring motor which drives a copper cylinder, upon which the treated paper is wrapped. It also includes a suitable step-up transformer, providing for a choice of primary voltages from 110 to 550 volts.

This device has an inherent error of one-half cycle for the reason which is brought out graphically in Fig. 7. With this limitation, however, it is still sufficiently accurate to give a valuable check on most short-time welding operations and is particularly valuable where the control is of a synchronous type so that the set of waves being measured in each timing period is duplicated each time.

Factors Governing Accuracy of Results

The statement has been made in published discussions of spot welding control that the error involved in control by means of contactors is on the order of three cycles. Although this statement is doubtless correct in some instances, it does not correspond to the performance obtained at the present time in a number of installations. Evidently, in any case where there *is* a variation of 3 cycles in the timing, the percentage error on welding at timing less than about 10 cycles becomes very large, but it is entirely feasible to control contactors to a variation in timing of only one-half cycle or less.

An able analysis of the problem of accurate spot welding control by a contactor is given in an article, "Resistance Welding of Aluminum and Its Alloys," by D. I. Bohn and G. O. Hoglund, *Welding Engineer*, 1933. This article cites three principal reasons for inaccuracy with the usual installation:

1. Error due to variation of the point in the A.C. cycle at which the contactor coil is energized (the article states that this alone causes variation in timing up to nearly one-half cycle).
2. Error due to variation in the opening time of contactor coil circuit. If this circuit is opened at the instant of zero magnetic flux in the contactor magnet, the contactor drops with minimum delay, but if at the instant of maximum flux, the collapse of magnetic flux induces a current in the shading coil which may hold the magnet in for several half cycles.
3. Errors due to variation of the point of opening of the main contacts of the contactor relative to the power wave. The article states that if this circuit is interrupted at the moment of maximum flux in the transformer core, there is an instantaneous heavy discharge of welding current due to this rapid flux collapse. This current was in some cases three times the r. m. s. value of the normal welding current.

In order to meet these difficulties recourse was had to a number of expedients for which reference should be made to the original article.

It is evident from the first and second of the above items that if an electronic timer is to be suitable for very short time work it should have the property of both closing and opening the circuit to the welding contactor coil at a definite point in the cycle. It does not so much matter at what point this is; the exactness of repetition depends primarily on its being the same point in the wave each time. Further, the response of the welding contactor to the timer should be sufficiently fast and accurate so that it, in turn, can be made always to open its circuit at approximately a given point in the current or voltage wave. The question of a contactor which will respond in this way will be considered first.

Figure 8 is from an oscillograph film taken of the timer of Fig. 4 in regular production on automobile body work. It shows a lag of about 2.5 cycles between the application of voltage on the contactor coil and the instance that the main contacts thereof touch. Similarly, there is a margin of about 2.0 cycles between the cutting off of current to the contactor coil and the opening of the main contact. The contactor used in this case is an ordinary standard type having an arc gap of about $^1/_2$ in. By detailed revisions of contactor design we were able to reduce the contactor closing time from 2.5 cycles to less than 1.5, and the opening time from 2.0 cycles to about 1.3.

One of the principal factors establishing the amount of arc gap provided in an A.C. contactor of conventional design is the rebound obtained when the contactor opens. The amount of arc gap must be sufficient so that this rebound is in no danger of causing the contact tips to touch a second time. In this special design of contactor for welding this problem is solved in a different way. Instead of permitting the bounce and using a wide arc gap to make it harmless, the bounce is damped out by a snubbing device and a very small arc gap is used. This snubbing device consists of a special form of stop against which the tail piece of the contactor magnet falls when in the open position. This stop consists of a central piece held in compression between two friction surfaces by compression springs. When the contactor opens, the blow of the tail piece against this stop is sufficient so that the central piece moves back, allowing the main contacts to open to something like $^1/_2$-in. arc gap, while the return of the central piece of the stop is greatly retarded by the friction so that the contactor is brought back gently to the position of about $^1/_8$-in. arc gap. In addition to this feature, the welding contactor has improved bearings of very long life, extra heavy contacts and extra heavy contact pressure to assist in rapid opening. There is thus provided a contactor which can be counted upon to be sufficiently fast and accurate to respond accurately to the timer with which it is associated.

The fact that the timer of Fig. 2 is able to handle this contactor to best advantage is shown by reference to Fig. 9. It will be noticed in this film that the circuit to the contactor coil is made and broken at the same points in the cycle each time, and similarly that the same thing is true with regard to the making and breaking of circuit through the main contacts of the contactor.

The fact that the contactor can be made to open repeatedly at a definite point in the wave leads to the next step in the development on which we are engaged at present. This is to provide a phase-shifting device to provide power supply to the timer and to the contactor coil, so that the phase of operation of the contactor can be adjusted relative to the main welding current and voltage and so provide a simple and convenient means of adjusting the operation of the contactor so that it opens its contact for minimum arc. In heavy work this should reduce the maintenance on the contactor sufficiently to warrant the investment in the phase shifting device.

Objection will probably be raised to the above method that maintaining such synchronous operation of a contactor will involve delicate adjustments and highly skilled maintenance and is, in short, a laboratory rather than an industrial proposition. This, however, is not necessarily the case at all. The inherent action of the timer, regardless of adjustment, is to close and open its circuit at a definite point in the wave, because that is the unavoidable characteristic of the gaseous tube which forms the heart of the apparatus. Regardless of adjustment, therefore, the main contacts of the contactor are also going to open at a definite point with regard to the welding current and voltage. It is true that this point will shift from time to time with contact wear, but this shift will not necessarily be rapid, especially if contact burning is kept to a minimum by periodical adjustment of the phase-shifting device so as to bring the contactor to operate at the point of minimum arc. Such adjustment will require no particular skill as it will merely require watching the contactor in operation and turning the lever of the phase-shifting device until the smallest arc is obtained on successive operations.

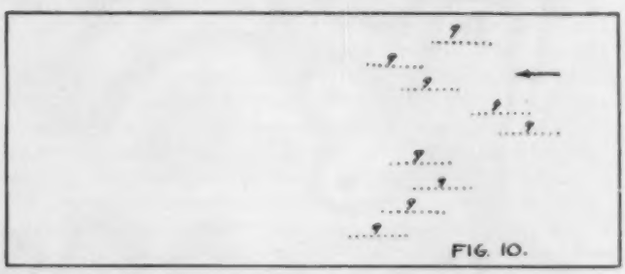


FIG. 10.

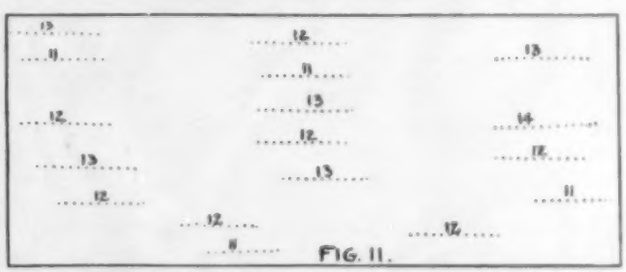


FIG. 11.

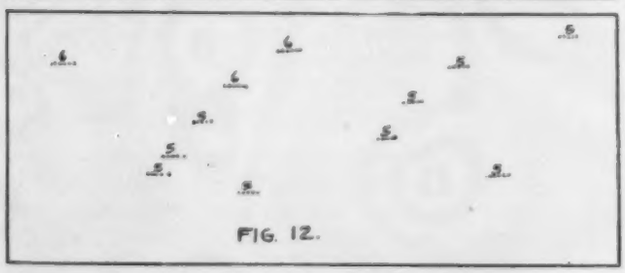


FIG. 12.

FIG. 13

Some Typical Accuracy Test Results

Readers will doubtless be interested in some typical accuracy results obtained with the puncture tests as described above. Unfortunately this device has only been available for a short time, and our results in this line are not particularly comprehensive.

Figure 10 shows a typical puncture test record made with the type of welding contactor described, controlled by a gaseous tube timer of slightly more elaborate type than that shown in Fig. 2. The repetition here is exact, both as regards number of cycles and point in cycle at which the contactor opens and closes.

Figure 11 shows a typical puncture test made on a welder having a motor-driven contactor which completes the welding circuit (no magnetic contactor used). The driving motor was not synchronous, and the same motor served to operate the electrodes. The record of timing obtained in a case like this is a sort of statistical proposition, and the results obtained on the sheet shown and others totaling 80 welds are given in the following table:

Period in Cycles	Number of Welds at Given Period
5.0	12
5.5	28
6.0	29
6.5	10
7.0	1

It will be seen that there is about an equal chance of getting 5.5 or 6.0 cycles, with a lesser chance of falling outside in either direction with 5.0 or 6.5 cycles. This is a machine selected at random and there is no definite assurance that the results are typical, although they are believed to be. Bearing in mind the error of $^1/_2$ cycle inherent in the puncture test method, and neglecting the single reading of 7.0 cycles, it is evident that the real timing variation on this particular machine is 1.0 cycles at an average time of 5.75 cycles. (It is hoped that by the time of actual presentation of this paper, puncture test results will be available from a number of other mechanically driven machines, particularly those involving magnetic contactors.)

Perfect repetition of timing like that illustrated in Figs. 9 and 10 involves somewhat more elaborate apparatus than is provided in the standard commercial devices like Figs. 2 and 4. These latter do allow a certain small error in timing and like many other engineering questions the choice between them and a more elaborate and accurate apparatus is a matter of economic balance.

Figures 12 and 13 show typical puncture test records made with the timers of Figs. 2 and 4, respectively. As at present developed, the maximum variation of timing obtained with stock timers of this type is as given in the following table:

Nominal Period, Cycles	Maximum Variation, Cycles
3	0.5
12	1.0

Conclusion

It is hoped that the information given above will clarify the status of the use of magnetic contactors in spot welding, both in the older and less difficult fields typified by welding periods of $^1/_4$ second or longer, and in the more recent and difficult developments involving the application of welding voltage for a period on the order for $^1/_{20}$th second and even less.

Pressure Regulators and Regulation Problems

By GEORGE M. DEMING*

†Paper was presented at Fall Meeting, A. W. S., in Detroit, Oct. 2nd to 6th, by G. M. Deming, of the Apparatus, Research and Development Department, Air Reduction Co., Inc.

Fundamental Requirements

THERE are five fundamental requirements for oxy-acetylene welding and cutting regulators:

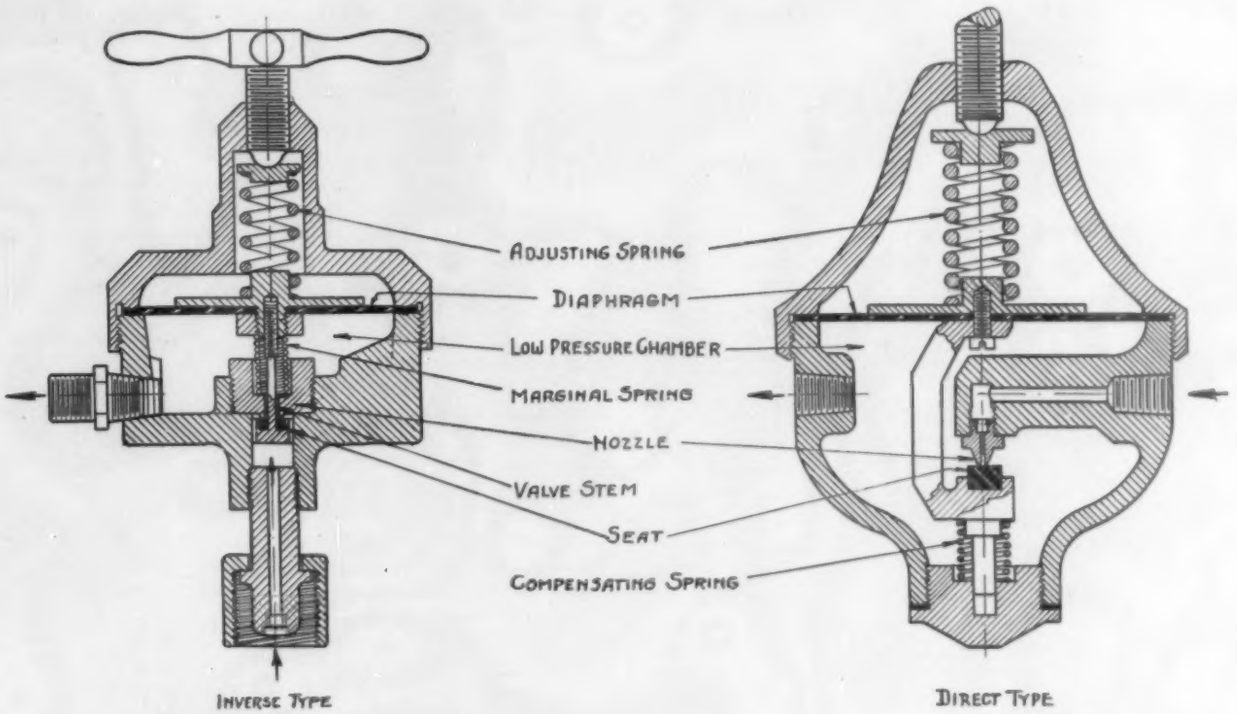
1. The pressure of the gas compressed in the cylinders must be reduced to a relatively low delivery pressure.
2. The delivery pressure must be maintained at a fairly constant value independent of all disturbing influences.
3. Means must be provided to adjust the delivery pressure to any desired value.
4. Maintenance must be reduced to a minimum.
5. The regulator must be safe under all conditions of normal use and as fool-proof as possible.

Manner of Operation

Although details differ widely, virtually all pressure regulators embody certain fundamental principles, which may be appreciated by reference to Figs. 1 and 2. Thus, all regulators contain some kind of a valve which may be set to throttle the flow of the gas, and in this manner fulfill the first requirement listed above. Whenever the delivery pressure of a regulator tends to fall for any reason whatsoever, a pressure-responsive element, such as a flexible diaphragm, opens the regulator valve slightly and thus permits an increased discharge of gas into the regulator. This results in a restoration of the pressure level of the gas being discharged from the regulator. In case of a tendency toward an excessive delivery pressure, the reverse process takes place. In this manner the second requirement is fulfilled.

As illustrated by the typical constructions of Figs. 1 and 2, the delivery pressure may be adjusted by varying the stress of an "adjusting spring" by means of an "adjusting-screw." If the adjusting spring is under considerable compression, it will exert a relatively heavy thrust against the diaphragm and hence require a relatively high delivery pressure to hold the valve closed sufficiently to throttle the gas delivery so that the discharge from the cylinder into the regulator is no greater than the rate at which gas is being withdrawn from the regulator. On the other hand, if the adjusting spring be only slightly compressed, a relatively low delivery pressure will be the result. In this manner the third requirement is fulfilled.

Because of the hazards which would be involved if special precautions were not taken to prevent the escape of gas when a regulator is attached to a cylinder but not in use, pressure regulators are customarily equipped with a valve spring (the marginal spring of Fig. 1 or the com-



Typical Welding Regulators

pensating spring of Fig. 2) which will urge the valve closed when the stress of the adjusting spring has been completely relieved by releasing the adjusting-screw. This is one of the means by which the safety requirement is fulfilled.

Other aspects of the safety question, as well as the means by which the minimum maintenance requirement is met in successful and practical regulator designs, will be more clearly understood after a survey of the general theory of regulation as well as many of the practical problems involved.

Classification

With regard to structure it will be found convenient to classify oxyacetylene regulators as follows:

1. Inverse pressure regulators (Fig. 1).
2. Direct pressure regulators (Fig. 2).
3. Compound or double reduction regulators in which two regulators are connected in series.

An inverse pressure regulator is one in which the thrust of the high-pressure gas is in such a direction as to tend to close the seat against the nozzle (see Fig. 1). A direct pressure regulator may be defined as one in which the thrust of the high-pressure gas is in such a direction as to tend to force the seat away from the nozzle (see Fig. 2). In a compound regulator the two individual regulators of which it is composed may both be of the direct type, both of the inverse type, or one may be of one type and the other of the other type. As a rule the two regulators are built into a compact unitary construction (see Fig. 8).

Effect of Variations of Inlet Pressures

Most pressure regulators are imperfect in that the delivery pressure undergoes a perceptible—and often a very undesirable—change as a result of normal variations in inlet pressure. The inlet pressure, of course, slowly decreases as a result of cylinder drainage if the source of supply be compressed gas cylinders. If the source of supply be an acetylene generator or if the regulator is being worked off of a feeder line small enough to involve a marked pressure drop, which is also supplying a highly variable load (i.e., such as welding and cutting torches), the inlet pressure may in some instances fluctuate enough to cause disturbances in the delivery pressures. The influence of the inlet pressure upon the delivery pressure may be understood by referring to Fig. 3, which is a schematic representation of a typical regulator including the disposition of the various forces which influence the regulating mechanism. At all times during the process of pressure regulation the thrust of the low-pressure gas against the effective area of the diaphragm, as illustrated by the arrows, p, plus the thrust, f, of the compensating spring, must exactly balance the thrust of the high-pressure gas upon the regulator seat, as illustrated by the arrows, P, plus the thrust, F, of the adjusting spring. Any decrease of the high-pressure reaction against the regulator seat will, therefore, at least temporarily upset this equilibrium of forces. Consequently the regulator seat will be urged toward the regulator nozzle, and the rate at which the gas discharges into the regulator will be diminished accordingly. The low pressure, p, will then diminish until the balance of forces is again restored. Similarly, referring to Fig. 1, it will be seen that in the case of an inverse pressure regulator a decrease of inlet pressure will likewise bring about an unfavorable deviation in delivery pressure, but in this case the delivery pressure will rise instead of fall because the thrust of the high-pressure gas upon the movable element is in the same direction as the low-pressure gas reaction.

Dimensional Effects

In view of the relationships just described, reference to Fig. 3 should make it evident that the detrimental effect of a varying inlet pressure is less the greater the ratio of the diaphragm area to the cross-sectional area of the

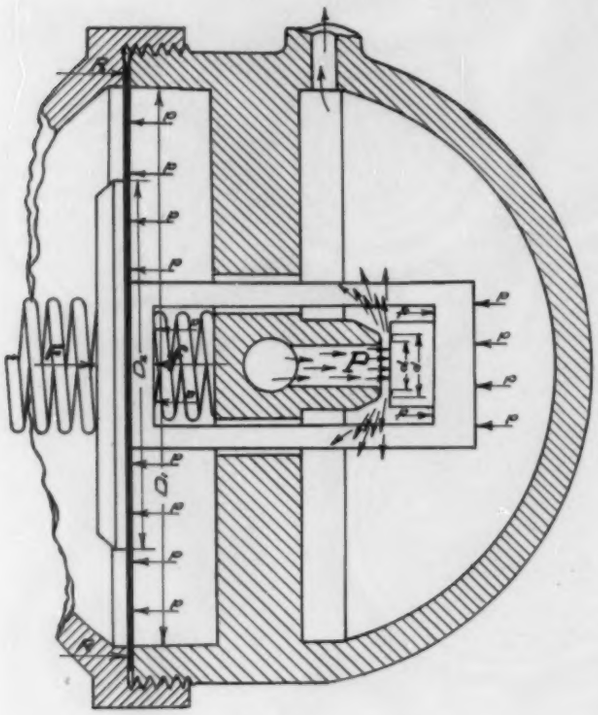


Fig. 3

nozzle discharge port. That is, the quality of regulation is improved the larger the diaphragm or the smaller the nozzle. But there is a decided limit to the extent to which a designer may make use of enlargement of the diameter of the diaphragm without creating a regulator which is too heavy and bulky. An increased diaphragm diameter forces an increase in the size of many other parts, so that the weight of the regulator increases almost as the cube of the diaphragm diameter.

There is also a rather definite limit to which the diameter of the nozzle orifice may be reduced, for the nozzle must be large enough to handle the maximum volume of gas which it will be called upon to discharge, and do so without giving rise to an excessive pressure drop.

Regulation End-Point

The disadvantage of using an excessively small nozzle is most apparent when the regulator inlet pressure is very low. When the inlet pressure is very high as when a full cylinder is in use, the density of the gas discharging from the nozzle is relatively great and, hence, the discharge capacity of the nozzle is considerably greater than it is at low cylinder pressures. This simply means that the regulator can handle a much greater load at higher cylinder pressures than it can when the cylinder pressure is rather low. It must be obvious that for any given load, that is, for any given volume rate of discharge, there must come a time during the progressive drainage of the cylinder when the pressure drop through the regulator nozzle has increased so much that with any further decrease of cylinder pressure it will not be possible for the nozzle to discharge the gas rapidly enough to maintain the delivery pressure. In other words, for any given outflow there is a cylinder pressure below which the regulator will not function as a pressure regulating device. This is conveniently referred to as the "regulation end-point" for the particular rate of flow involved. The regulation end-point for the maximum rate of flow for which the regulator is designed is hereinafter designated as the regulation end-point of the regulator, although it must be clearly recognized that for more normal demands than the maximum the actual regulation end-point would be much lower than the specified value. In many regulators, particularly in the better types of double-reduction regulators as well as for most cutting regulators, the regulation end-point is determined to some extent by the operating pressure which is being used. Hence, where the regulation end-point of a regulator is given, unless otherwise stated, it should be assumed that the value is for the maximum delivery pressure for which the regulator is designed.

The regulation end-point of a regulator is one of the most important measures of performance because it indicates whether the regulator is economical to operate. A regulator with a high regulation end-point is a regulator which will leave much unused gas in the cylinder when it finally becomes necessary to remove the regulator from the cylinder.

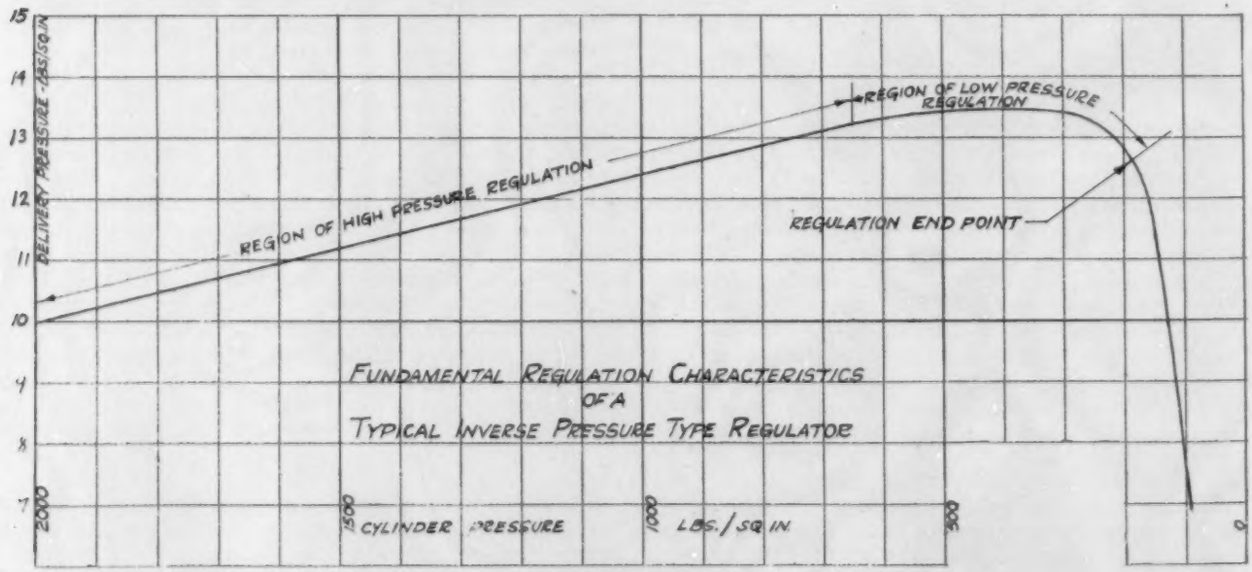
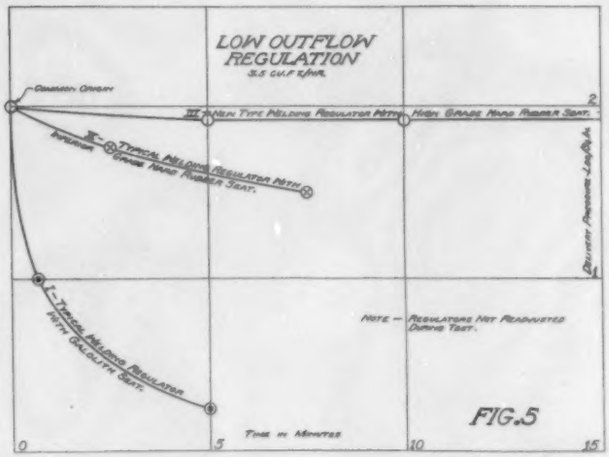


Fig. 4



Region of Low-Pressure Regulation

At an inlet or cylinder pressure above the regulation end-point but at relatively low cylinder pressure, the regulating characteristics of the regulator may depart considerably from what they are at the very high cylinder pressures. This lower cylinder pressure region will hereafter be designated as the "region of low-pressure regulation," and the upper region will be designated as the "region of high-pressure regulation." Now the region of high-pressure regulation is a region in which the cylinder pressure effect upon regulation, as previously described, is ordinarily the most important detrimental influence to be considered. In the region of low-pressure regulation, however, the phenomena involved become more complicated, chiefly as a result of the growth of specific volume of the gas with decreasing cylinder pressure, or more directly because of the concomitant increasing seat displacement. In general, the increasing seat displacement results in an inward movement of the diaphragm and, therefore, in a loss of stress in the adjusting spring. The over-all effect is that the delivery pressure decreases accordingly (see Figs. 4 and 10).

Without going into detail it seems well to point out that for heavy outflows and particularly for regulators with stiff springs or metal diaphragms, the deviation from correct pressure regulation may be so serious in this region of low-pressure regulation as to very seriously limit the usefulness of the regulator.

Comparison of the Direct Pressure and the Inverse Pressure Regulator Types

By reference to Fig. 4 it will be seen that in the region of low-pressure regulation the regulation errors, resulting from increasing seat displacements, and the high-pressure regulation errors, resulting from degradation of inlet pressure, tend to compensate each other. In a direct-pressure regulator the two errors are additive. To this extent the indirect-pressure design is superior to the direct-pressure design. In practice, however, this advantage is usually negligible, provided both the regulators are properly designed. This is because the delivery pressure decreases more and more rapidly with falling cylinder pressure or with increasing rates of flow, so that if the two types of errors are fully compensative under one condition, they are very far out of balance at nearly every other condition of practical application.

On the other hand, it will be found that if both types of regulators are designed for maximum attainable regulating efficiency, the direct type will in general be found to give much more satisfactory regulation than the in-

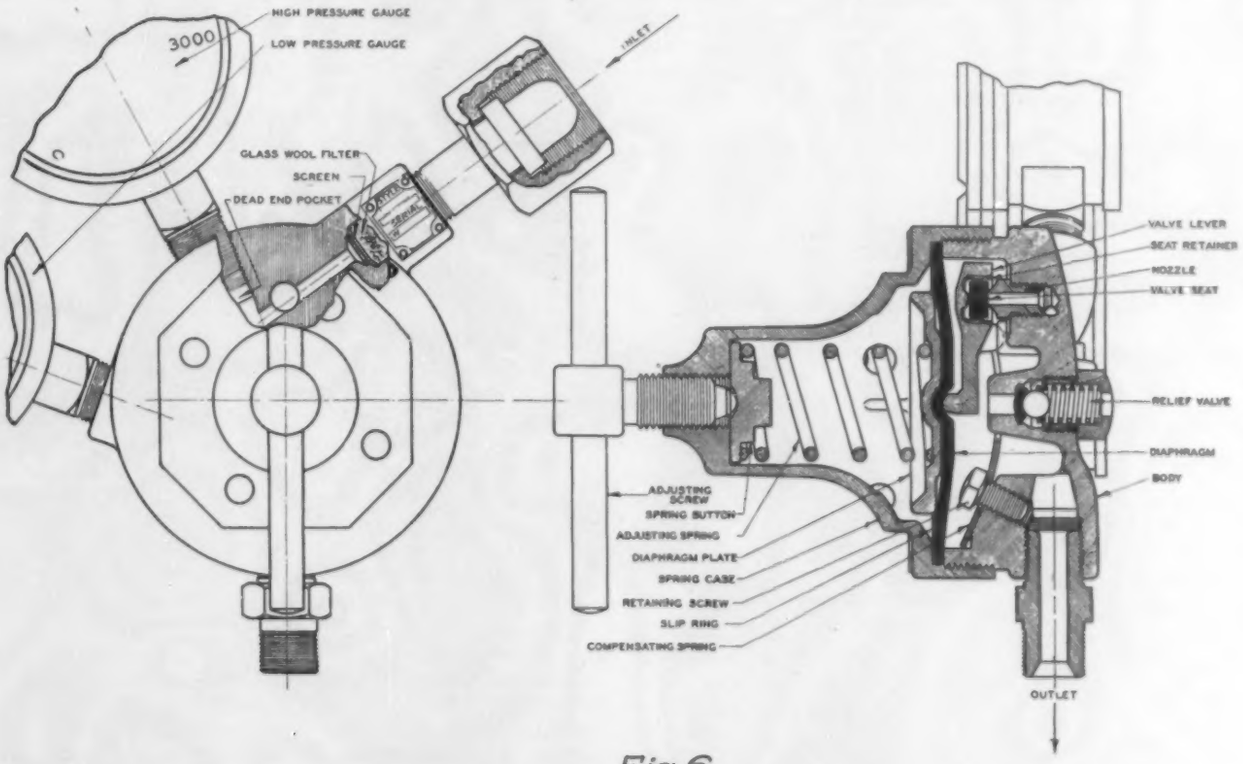


Fig. 6

IMPROVED DIRECT PRESSURE TYPE WELDING REGULATOR

direct type. (The one important exception is that of line regulators to be discussed in later paragraphs.) The reason for this condition is to be found in a consideration of the practical effect of taking up some of the space within the discharge port in the nozzle (or equivalent element) for the thrust pin which is used in the inverse type of construction. If the regulation end-point is to be the same in the two different types of regulators, the discharge cross-sectional area of the two types of nozzles must be maintained approximately equal by enlarging the nozzle of the inverse pressure type of regulator in order to accommodate the thrust pin. But the increased area of the seat or movable element thereby subjected to the thrust of the high-pressure gas necessarily involves more serious deviations of delivery pressure in the very important region of high-pressure regulation.

Seat Recovery

For very low out-flows the regulating characteristics of many commercial regulators are frequently very poor. This is apparently largely owing to the fact that it has not been clearly recognized that for lead-burning and light welding regulators it is not purely a question of employing small nozzles. Many of these regulators make use of types of seat material whose plastic properties are so pronounced that the material continues to change its shape long after a load has been applied to it or removed from it. When a regulator is not in use and its adjusting screw is released, the seat is forced against the nozzle by means of the compensating or marginal spring. With many typical seat materials the stress at the point of engagement between the seat and the nozzle is so great that the seat material in this region yields somewhat, leaving a more or less permanent impression of the nozzle lip in the surface of the seat. If, after the seat has thus accommodated itself to the pressure of the nozzle lip, the regulator is placed in service the seat material, having been relieved of this pressure, will at once begin to regain its original shape. The recovery is very rapid at first but becomes slower as recovery progresses. The result is a partial throttling of the gas discharging from the regulator nozzle. This throttling, of course, is very prominent at first but becomes less so with the lapse of time. For the very low rate of flow covered by Fig. 5, the pernicious effect of seat recovery upon regulation may be readily detected as much as an hour after the regulator has been placed in service. Hygroscopic material, such as indurated fiber or casein products, is much worse so far as seat recovery effects are concerned than hard rubber, if the gas contains appreciable quantities of moisture.

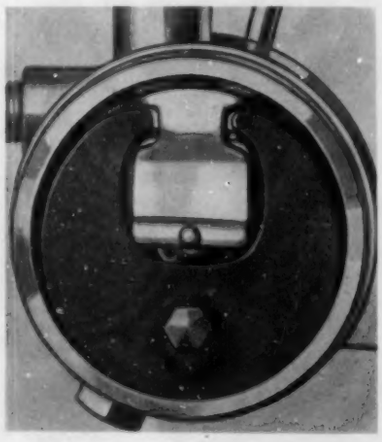


Fig. 7

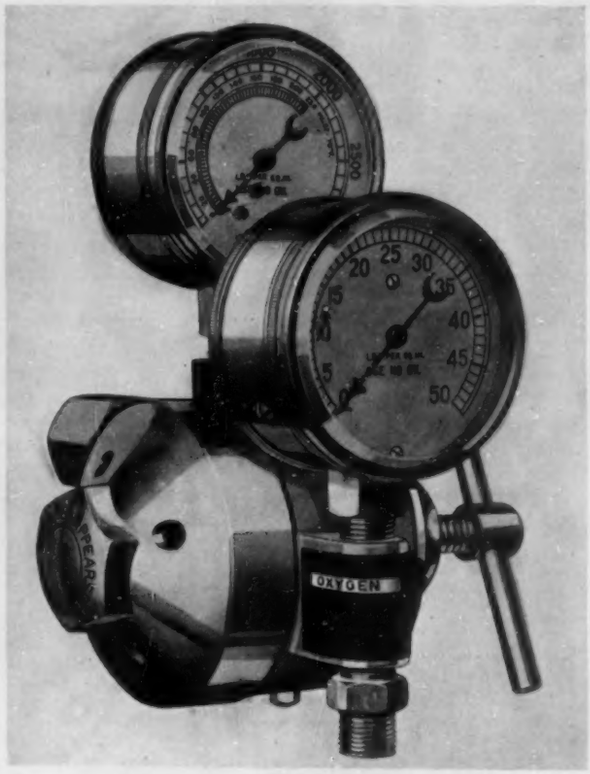


Fig. 8

It is interesting to note that for light out-flows the seat recovery is frequently many times the magnitude of the seat displacement. Thus, for the lighter welding outflows, the seat displacement rarely exceeds a few hundred thousandths of an inch at upper cylinder pressures, whereas even a non-hygroscopic seat material may recover several ten-thousandths of an inch. The seat will merely continue to recede from the nozzle keeping approximate pace with the recovery of the seat material. But this movement results in decreasing the compression of the adjusting spring so that the delivery pressure of the regulator falls. A worth-while observation in this connection is that if the regulator nozzle is too large, the seat displacement for a given out-flow will be less than if a smaller nozzle is used. Consequently there is much to be gained by employing a regulator proportioned for the service intended.

Although seat-recovery phenomena are most severe with low out-flows, they are prominent enough even in the case of moderately heavy welding outflows to be decidedly troublesome during the first few minutes of operation if improper seat materials are employed.

Curve III of Fig. 5 illustrates the performance of the regulator of Fig. 6. Much of the superiority of the low-out-flow regulation of this regulator is due to the selection of a non-hygroscopic seat material of very low recovery characteristics.

Precooling

The fundamental regulation characteristics of a regulator, such as described in the preceding sections of this article, are often profoundly modified by certain disturbing influences among the most important of which is precooling. High-pressure gases expanding from a regulator nozzle give rise to considerable refrigeration effects so that the gas approaching the nozzle is precooled by chilled walls of the high-pressure passage in the regulator

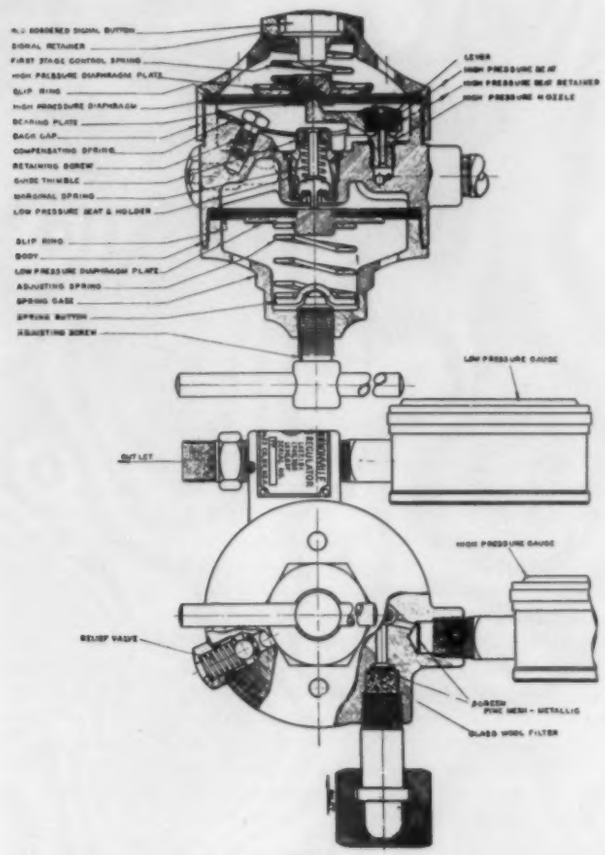


Fig. 9

body. Hence, minute droplets of condensate are precipitated on the walls of the inlet passage and are then swept into the regulator nozzle.

If the atmospheric temperature be less than forty or fifty degrees Fahrenheit, the precooling may be sufficient to freeze particles of water which have precipitated on the cold walls of the approach passage to the nozzle. Such freezing, even when the amount of water vapor originally contained in the gas is rather small, may readily obstruct the nozzle discharge so effectively that the delivery pressure will abruptly fall. With falling delivery pressure the regulator diaphragm will move inwardly and the seat displacement will accordingly increase. Soon the seat displacement becomes great enough to permit the small crystals of ice to be violently discharged from the nozzle. There then follows a suddenly increased rate of discharge of gas from the nozzle, which is only stopped by the seat when the pressure reaches an excessive value. The result is repeated with usually severe disturbances of the delivery pressure.

But the seriousness of precooling phenomena is not confined to those cases in which the atmospheric temperature is as low as the forty or fifty degrees mentioned above. For even at the higher summer temperatures the precooling may be great enough where heavy flows are involved to precipitate moisture in the approach passages to the regulator nozzle. When it is considered that the normal displacement of a regulator seat from the nozzle at full cylinder pressure is, in the average welding regulator, usually a matter of only a few hundred thousandths and rarely over a few ten thousandths of an inch, it will be appreciated how effectually a single drop of water will block the discharge from the regulator nozzle. Consequently, even at moderate atmospheric temperatures, precooling may give rise to severe disturbances in the delivery pressure, although these will, of course, not be as severe as where actual freezing is present.

A satisfactory solution is to employ a compound regulator. Although the first stage of pressure reduction of such a regulator may develop some pressure fluctuations in cold weather, the second stage will practically eliminate such fluctuations from reaching the delivery hose. There are several reasons for this. One is that on account of the decreased density of the gas discharging into the second stage of the regulator the seat displacement for the second stage is much greater than for the first stage. The increased displacement permits small quantities of condensate to be readily discharged. Where a double reduction regulator is not available, the following precautions should prove helpful in minimizing precooling troubles. First, do not withdraw cylinders from a warm room and attempt to use them at once out-of-doors in a cold atmosphere. Until thoroughly chilled, the gas in the cylinders may contain traces of moisture or other condensates, but nevertheless enough to disturb the process of pressure regulation. Secondly, operate the regulators at as high a delivery pressure as practicable and throttle at the torch for the desired rate of delivery. Third, do not make use of regulators with excessively large nozzles, for on account of the very small seat displacements necessary with such regulators to discharge gas at any given rate, the space between the nozzle and the seat is more likely to become obstructed than with smaller nozzles.

Friction

Frictional disturbances are generally made evident by a considerable deviation of the regulation in the low pressure region from theoretical performance and by sudden pressure readjustments in this region. Any attempt to reduce friction in a regulator to a minimum by various mechanical artifices always results in another type of trouble which is variously known as "singing," "humming" or "chattering," according to its severity. An investigation of this phenomena indicates that there is a natural tendency toward instability in the movements of the regulator seat and that if vibration of the moving parts in the regulator is to be prevented some damping means are necessary. Friction ordinarily supplies the necessary damping forces. The precise mechanism of seat vibration in inadequately damped regulators appears to involve a suddenly increased high pressure gas thrust against the regulator seat in the region of the nozzle lip impression on the face of the seat when the seat is urged to a greater displacement by changes of gas pressure reaction against the regulator diaphragm. The increased thrust drives the seat yet further away from the nozzle and results in such an excessive discharge from the nozzle that the gas pressure beneath the diaphragm increases sufficiently to return the seat again to the nozzle with considerable force. It does not appear necessary to go into further detail concerning seat rebound, resonance conditions, etc. It is sufficient to note that unless there is a certain amount of damping the movements of the seat may become so unstable as to result in very rapidly repeated movements of the seat toward and away from the nozzle, which are not only troublesome because of the noise involved, but which may also shorten the life of the seat if too severe and if allowed to continue too long. In the ideal regulator there should be no more than just enough friction to damp the seat movements during regulation of the heaviest flow which the regulator is designed to handle.

In studying the problem of damping it has been found that damping in typical regulators of the type illustrated

by Figs. 1 and 2 is of a very haphazard character. It arises from the lateral distortion or buckling of the helical springs when under compression. If the adjusting spring and the compensating spring, for instance, are distorted in such a manner as to both urge the seat-carrying means in the same lateral direction, then damping will be at a maximum, but if the lateral forces arising from these springs are opposed, then damping will be at a minimum. In the regulator illustrated by Figs. 6 and 7, a highly satisfactory damping means has been developed which is uniform for all manufacturing assemblies, in which a crescent-shaped stamping of sheet spring steel (the compensating spring) bears on a valve-actuating lever in a region intermediate between the projected center line of the nozzle and the two ball fulcrums on which the lever rocks. Thus, a very definite portion of the compensating force is utilized to effect damping at the lever fulcrums. The high quality performance of this regulator is due in no small measure to this feature.

Line Regulators

Regulators, which are used on individual outlets of a distributing line from a manifold or an acetylene generator, are in many important respects considerably different than the regulators which operate directly from compressed gas cylinders, owing to the much lower inlet pressures which are ordinarily involved. One consequence of the lower inlet pressures is that less damping is required than in cylinder regulators. Moreover, frictional errors are usually more serious in line regulators than with cylinder regulators, so that it is quite essential that less damping be employed in these regulators than in cylinder regulators. This is particularly true of acetylene line regulators. These must operate on very low inlet pressures, the maximum pressure permitted by the Board of Fire Underwriters being 15 lb. per sq. in.

Another result of the relatively low inlet pressures utilized for line regulators is that the direct pressure design does not possess the marked advantage over the inverse design that it does in the case of cylinder regulators. In fact, in the case of acetylene line regulators the advantage appears to be in favor of the inverse type. This is chiefly because in the case of a cylinder regulator the inlet pressures are usually very high, but in the case of an acetylene line regulator the inlet pressure is so low that seat movements with varying inlet pressure are very pronounced.

The question of excessively high regulation end-point has not usually proved so important in the case of oxygen line regulators as it has in the case of acetylene line regulators. This again is because with acetylene line regulators the line pressure is low. It is essential that the regulation end-point for the maximum out-flow, which the acetylene line regulator must handle, be lower than the line pressure. Otherwise the regulator cannot function as a means for regulating pressure. The problem becomes more complicated in the case of the acetylene line regulator than in the case of cylinder regulators. For the former there is a very prominent deleterious effect of delivery pressure upon the discharge capacity of the regulator nozzle when the inlet pressure is very low. Because of this it is more convenient when considering heavy out-flows to think of the capacity of an acetylene line regulator as limited by insufficiency of maximum practicable operating pressure rather than by excessive regulation end-point in the usual sense. The regulator may, for example, be practically worthless as a pressure regulator for heavy welding out-flows if the generator and line pressure are as low as 11 or 12 lb. per sq. in. and the acetylene pressure required by the particular torch and largest tip is as high as 8 or 10 lb. In this sense, therefore, regulation end-point is especially important for acetylene line regulators.

Double-Reduction Regulators

The first stage of a double-reduction regulator should obviously involve the principles of design applicable to cylinder regulators. The second stage, on the other hand, should be designed according to principles appli-

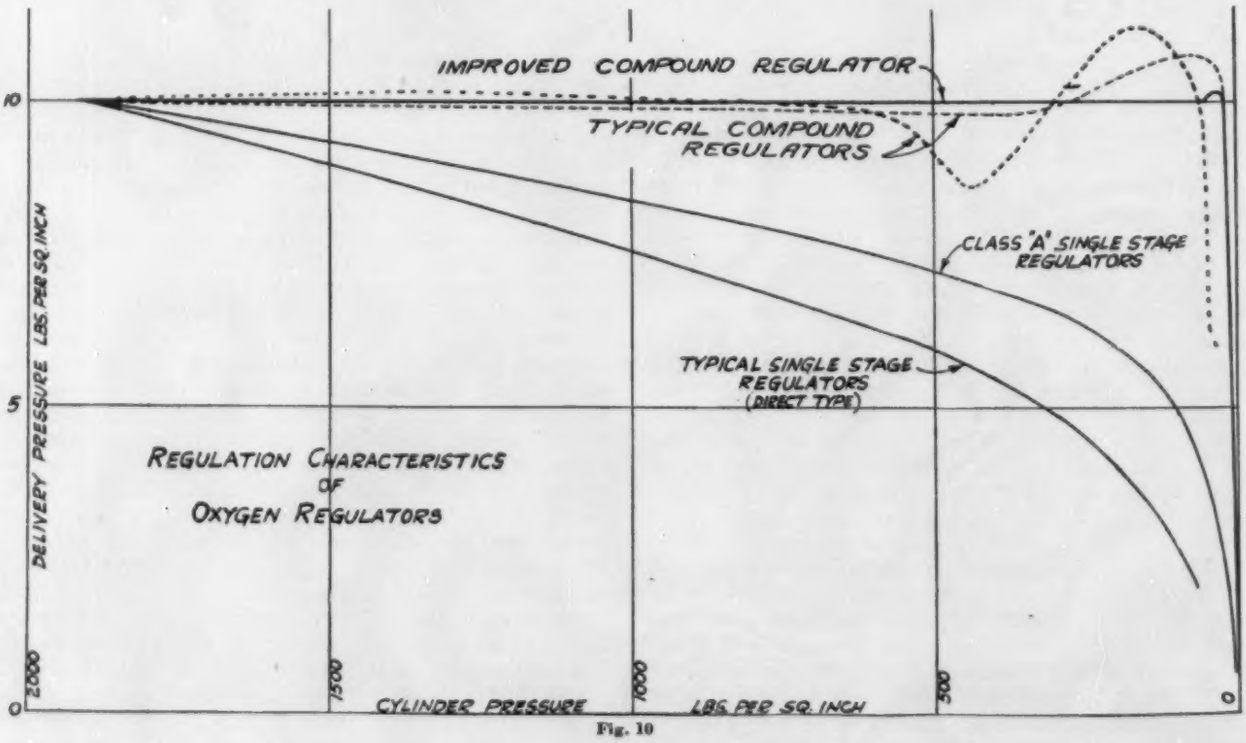


Fig. 10

Fig. 11

cable to line regulators. Consequently the direct pressure type of regulator is most suitable for the first stage and the inverse type is most suitable for the second stage. Of course, inasmuch as the delivery pressure of the first stage is not necessarily adjustable and remains at a fixed level, it is possible accurately to design the second stage to work on the definite pressure delivered by the first stage. The result is a much more satisfactory and efficient arrangement than is obtained where two regulators are connected in series and the adjustment of the first regulator left to the discretion of the operator.

Figures 8 and 9 illustrate a double-reduction regulator which utilizes the previously described mechanism shown in Figs. 5 and 6 for its first stage and which utilizes an inverse pressure regulator for its second stage. Incidentally, this regulator is of exceptionally rugged construction as well as being of very compact design. It is extraordinarily precise in its regulation characteristics and its regulation end-point is unusually low (see Fig. 10). Its ability to withstand severe weather conditions is well illustrated by Fig. 11.

Static Increment

Closely allied with the theory of pressure regulation is that of static increment. By this is meant the amount by which the delivery pressure of a regulator in satisfactory working condition rises whenever the discharge from the regulator is blocked. This is obviously the pressure rise which is necessary in order that the regulator seat may be pressed against the regulator nozzle with sufficient force to stop the discharge of the high-pressure gas.

The question of static increment is important because, for one thing, at very low rates of flow the regulator seat may not be displaced from the nozzle; the valve may permit of a sufficient discharge simply by virtue of the ability of the gas to seep between the seat and the nozzle while the two are in actual engagement at most points. Under these conditions it will be found that a regulator with a large static increment is one that is very unsatisfactory in its ability to regulate the delivery pressure for small out-flows. In order to seal a nozzle hermetically against further discharge the seat must be urged against the nozzle lip with sufficient force to stress the seat material in contact to a pressure which is at least as high as the pressure of the high-pressure gas. Otherwise the gas will seep through. In practice it has been found that owing to such factors as non-homogeneity of the seat material a considerably higher pressure is required. Thus, it is often found that for service with gases at 2000 lb. per sq. in., the seat material must be stressed to a value higher than 3000 lb. per sq. in. in the region of the nozzle lip. If the compressive modulus of elasticity of the seat material is very low, then the seat movement necessary to realize this stress may be so great as to involve a considerable increase in the stress of the adjusting spring. Such an increase will, of course, only add to the static increment. On the other hand, a seat material with a very high modulus may be so hard as not to readily conform to the shape of the nozzle lip nor to care for dirt or foreign material which may sometimes be present.

Creep

If the regulator is not in satisfactory working condition, there may be added to the static increment a further pressure increase, which, in comparison, develops rather slowly. This is usually known as "creep." It may result from an imperfect design of the seat-carrying means, the presence of dirt, scale, or other foreign material, or from the use of faulty seat material.

It is, of course, essential in a regulator for compressed gases that the seat shall squarely and accurately engage the nozzle lip if it is to be effective in hermetically closing the nozzle without the application of an excessive force. Ordinary machining and assembling manufacturing tolerances are usually insufficient to guarantee a square closure of the seat against the nozzle. It is, therefore, desirable in most designs to provide some special means for "seat accommodation" that will allow the seat to accommodate reasonable manufacturing variations.

In addition, for best results, it is necessary to ensure what, for the want of a better term, will be referred to as "seat alignment." That is, it is necessary to provide means which will prevent any eccentric loose play in the movements of the seat as it engages the nozzle. Otherwise the seat will not be presented to the nozzle in such a manner that the nozzle lip impression in the face of the seat is accurately fitted to the nozzle lip. Unless this is done the valve will continue to leak until sufficient pressure is developed to force a tight closure. In other words, the regulator will have a tendency to creep.

In the regulators of Figs. 6 to 9, inclusive, seat accommodation is provided by permitting the high-pressure

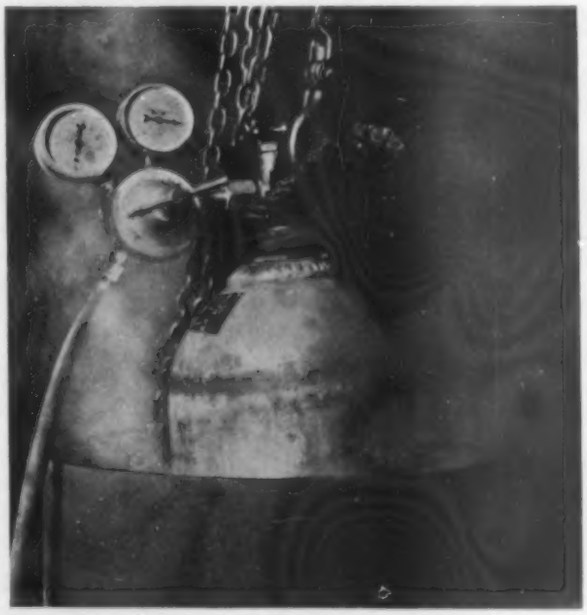


Fig. 12

seat to rock on a welt in the bottom of the seat-carrying cavity at the end of the lever, the seat being retained in position by a resilient metal seat retainer. Positive seat alignment is secured through the nature of the lever and compensating spring assembly in which the rounded ball fulcrums of the lever are urged to the lowest possible position in the conical fulcrum cavities machined into the regulator body, thus eliminating all loose play.

Filters

Fine woven wire strainers of 100 or 200 mesh are frequently employed at the regulator inlet in an attempt to remove foreign material. The results have been only moderately satisfactory. The reason for this is obvious when it is considered that the seat displacement is usually so small that particles which would readily pass through the finest of wire strainers may be retained between the nozzle lip and the surface of the seat. Consequently, efforts have been made to prolong the life of the regulator seat by selecting seat material which to a considerable degree will accommodate foreign particles by permitting them to become embedded in the surface of the seat when the latter is forced against the nozzle lip. There is a minimum hardness which is permissible in accomplishing this object, since it has been found that a material such as babbitt, which will accommodate the foreign material as a result of a certain degree of plastic softness, is not very satisfactory. If the material is soft enough to readily accommodate these particles, it is too soft to prevent a slow plastic yielding when the seat is pressed tightly against the nozzle. The most satisfactory materials have thus been found to be those which possess a certain degree of resilient softness (i.e., a moderately low elastic modulus). For many years certain organic materials such as caseinite were used, but owing to the hygroscopic nature of such materials any moisture in the gas served to soften seats excessively under certain conditions.

The deleterious effect of softened seats upon low outflow regulation has already been described. In addition to this it frequently happens that regulator seats develop cracks when permitted to dry when pressed tightly against the regulator nozzle by the regulator compensating spring while the regulator is not in use. The result is that, if a regulator with such a seat is then placed in service, the seat is incapable of stopping the discharge of high-pressure gas and consequently excessive pressures may develop within the regulator body.

What has just been said pertains chiefly to cylinder regulators. Because the inlet pressures are much lower in line regulators, the compensating or marginal stress need not be so great. Consequently these regulators may readily employ soft rubber seats. This is fortunate inasmuch as it is through the use of soft rubber seats that line regulators, when not provided with adequate filters, are capable of caring for the great quantities of dirt and scale which are frequently carried into them from long distributing lines.

Much careful research has indicated that aside from such inflammable and hygroscopic material as wool and cotton felt, glass-wool is probably the most efficient dust filter which may be employed in regulators. Glass-wool is not only free from the ignition hazard that is involved with inflammable filters, but being non-hygroscopic it always remains resilient. It is apparently by virtue of its resiliency that it does not cake over with dirt and scale in the manner that a metallic strainer does. Even after three years of severe service, a regulator equipped with a filter of this type has been found to offer no measurable restriction to the flow of the gas, although when opened the rear end of the filter was found to contain almost a thimble full of fine dirt and scale. During this interval there had been no seat failures. The effectiveness of this filter may be readily demonstrated by pouring fine iron or brass filings into the inlet of the regulator. Thereafter the regulator continues to perform satisfactorily although this same treatment would at once render the average regulator inoperative.

Safety Features

Because there is the possibility that excessive pressure may develop in a regulator, either through some abnormal action of the regulator itself or as a result of a flash-back, it is desirable that regulators be equipped with some device which will vent the regulator in event that the delivery pressure rises appreciably above normal. Frangible discs or readily rupturable diaphragms are sometimes used for this purpose, but a relief valve which will close tightly after the abnormal cause of the disturbance has been removed is to be preferred. Such a relief valve is illustrated in Figs. 6 and 9.

In the case of the regulator of Fig. 9, the relief valve relieves excessive pressure in both the first and the second stages. If an excessive pressure tends to develop down-stream from the regulator as a result of a disturbance in some other source of supply or because of a back-fire, the second stage seat will lift and permit the excessive pressure to be relieved through the first stage cavity and from thence through the relief valve. In the rare event that the excessive pressure arises because of a leak through the valve of the first stage, as for instance as a result of gross carelessness in repairing or assembling the regulator, the relief valve will serve to directly vent the first stage cavity.

Whatever the cause of the functioning of the relief valve, its operation will always be accompanied or preceded by a display of a red bordered signal button in the back cap of the regulator, which will be forced outward under the influence of the first stage diaphragm in event of any pressure appreciably higher than normal. In this manner a visible signal is given whenever any abnormal pressure has developed. The signal will remain displayed until it has been restored by hand. It indicates that at the first reasonable opportunity the regulator should be removed from service for inspection and possibly for repairs.

Seat Ignition

A rather serious type of seat trouble, but one which fortunately has been eliminated in modern regulator designs, is what has come to be known as "seat ignition." If oxygen at full cylinder pressure is suddenly admitted into an oxygen regulator by opening the cylinder valve, then considerable heat may be developed at the regulator seat as a result of the heat of compression imparted to the gas originally in the regulator inlet passages. Inasmuch as the most satisfactory seat materials are certain organic materials, such as carefully selected grades of hard rubber, the heated oxygen in contact with the seat predisposes the latter to ignition. It requires only the presence of some small inflammable foreign particles as fuses or a highly roughened seat surface to cause the seat to burn. The result, of course, is that gas at cylinder pressure will suddenly be admitted into the low-pressure cavity of the regulator.

It has been found that a glass-wool filter not only eliminates the aggravation of frequent seat replacements, but by preventing inflammable foreign material from reaching the regulator seat, it removes one of the contributory causes of seat-ignition. The fundamental cause, however, of excessive temperature rise at the

seat surface, may be removed by creating a cul-de-sac or dead-end pocket beyond the regulator seat. Figure 6 shows such a pocket under the high-pressure gage and a passage from this pocket communicating with the regulator nozzle. The effectiveness of this construction depends upon the fact that the heat developed in any passage suddenly flooded with high-pressure gas is localized in the extreme end of the passage. This phenomenon may be explained as follows:

Let it be assumed that a full oxygen cylinder pressure of 140 atmospheres is suddenly applied to the oxygen within the high-pressure passage of the regulator. Also assume the oxygen in this passage to have been practically at atmospheric pressure previous to the application of the 140 atmospheres of pressure. If there were no intermingling of the gas from the cylinder with that which was already in the high-pressure passage, these conditions would result in a temperature rise of nearly 1700° F. Of course, the actual conditions of flow of the gas through the regulator passage result in an intermingling of the two bodies of gas to such an extent that a much more moderate rise of temperature is the usual result.

In order to perceive clearly the nature of the phenomena involved, it must be observed that the volume of the original gas, which had occupied the entire inlet passage, has been reduced to $^1/_{140}$th of its original bulk. This small amount of hot gas has been diluted with gas from the cylinder. The latter is practically at room temperature except for the effect of the heat it has abstracted from the hot gas, because although it has undergone an approximately adiabatic expansion in flowing from the cylinder during which its temperature dropped to a very low value, it immediately thereafter underwent an adiabatic compression in which its temperature was restored practically to its original value.

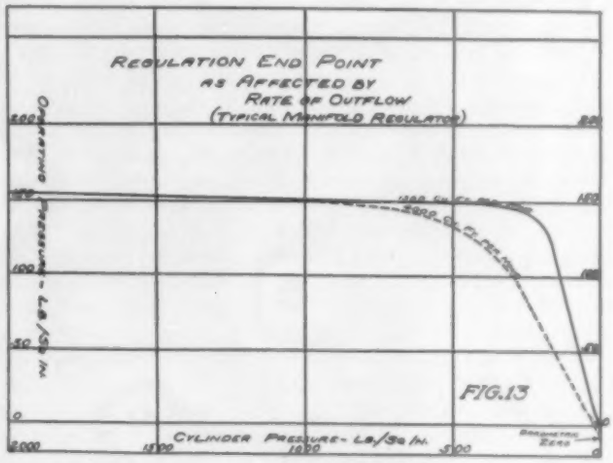
In actual practice the dilution of the hot gas is seldom uniform. Apparently the warmer portion of the gas is pushed to the end of the passage, namely, to the seat surface in the usual type of regulator construction or into the dead-end pocket in the case of the regulator covered by this description.

The effectiveness of this construction is illustrated by Fig. 12 which shows an oxygen cylinder and regulator (the latter equipped with dead-end pocket) being withdrawn from a bath of water which was heated to a temperature of 190° F. The regulator and oxygen cylinder were immersed in this bath for a period of one hour, and then hot oxygen at a pressure of 2500 lb. per sq. in. was suddenly admitted into the regulator from the cylinder. Although many different highly inflammable seat materials and inflammable substances within the nozzle were tried, it was found impossible to bring about seat ignition in regulators of this type.

However, in order that there might be no doubt that seat ignition had been entirely eliminated, a type of seat material was ultimately selected which is extremely resistant to ignition even when heated to temperatures much higher than was possible in the water bath. Since the dead-end pocket principle was first employed in regulator construction tens of thousands of regulators have been manufactured employing this means of seat protection, and yet not a single instance of seat-ignition in these regulators has been found.

Operating Range

Both safety and adequate performance are dependent upon not exceeding the proper operating range of a regulator or its normal discharge capacity. The range of the low-pressure gage is no index of the working-pressure range of a regulator. The manufacturers of pressure gages do not usually recommend the use of the gage throughout the full range of the graduated scale.



The question is frequently raised as to just "how much gas a (given) regulator will pass." Although this question can be answered, in a sense, the question and the answer are really not of much practical importance. If on rare occasions one should actually require such information, it should prove helpful to know that a regulator with a $^1/_8$-in. diameter nozzle orifice will at 2000-lb. cylinder pressure deliver over 20,000 cu. ft. of oxygen, or over 80,000 cu. ft. of hydrogen per hour. Provided the outlet is large enough to handle this flow at the given operating pressure, the regulator may clearly be said to be "passing gas" at these enormous rates of flow. Of course the regulator would have to be heavily damped to avoid humming. If the inlet pressure were not permitted to fall much below 2000 lb. and if precooling phenomena were not seriously involved, then the regulator might actually regulate the delivery pressure even at such tremendous discharge rates.

But the information which is usually required is more properly phrased as follows: "How heavy an outflow will this regulator handle if a regulation end-point of 200 lb. per sq. in. (for example) is not exceeded?" Figure 13 indicates why the regulation end-point is of fundamental importance when the discharge capacity of the regulator must be known. Note that for the regulator whose performance is indicated by Fig. 13, one would be correct in stating that if a regulation end-point of 200 lb. per sq. in. must not be exceeded, the regulator will not handle outflows much over 1000 cu. ft. per hr. On the other hand, if a regulation end-point of 500 lb. per sq. in. were tolerated, then the same regulator would handle 4000 cu. ft. per hr.

Selection of Regulators

From what has been said it must be apparent that the different classes of oxyacetylene regulators vary considerably from one another in their design characteristics. The use of the wrong type of regulator for a given job is very likely to result in either an inferior quality of pressure regulation or in an excessive end-point or both. Moreover under certain conditions the somewhat common practice of regarding a regulator as merely a "regulator" and not carefully selecting it for the particular job may result in damage to the regulator or even to an actual hazard.

Thus, one is certainly presumptuous, if nothing more, who uses a line regulator designed for an inlet pressure less than 200 lb. per sq. in. on a cylinder of oxygen where

the pressure is on the order of 2000 lb. per sq. in. From the standpoint of adequate regulation and a satisfactory regulation end-point, the opposite practice of using cylinder regulators as line regulators is equally to be condemned.

There are many obsolete designs of regulators still in use today that have long outlived their usefulness. The number of inferior welds which have been made as a result of a low quality of pressure regulation is, of course, impossible to estimate. Likewise, there is an unknown number of regulators still in use or used on the wrong job or misused in such a manner that considerable gas is wasted because of excessive end-points which are thus involved.

Thus, the first and second points to be borne in mind when selecting a regulator are:

1. The regulator must be of the correct class for the work intended, i.e., cylinder acetylene welding regulator, oxygen cutting line regulator, light duty oxygen manifold regulator, etc.

2. The regulator must be of the correct operating range and discharge capacity for the work intended.

Additional features which are worth considering are:

3. The quality of fundamental regulation should be adequate (i.e., the delivery pressure should not deviate too much with changing inlet pressure).

4. The regulation end-point at the maximum discharge rate for which the regulator will be used should be ascertained in advance.

5. Galolith and similar seats which may be softened in water should be avoided unless it is positively known that the regulator is to be used only with gases which contain a negligible amount of moisture.

6. Regulators with excessively stiff adjusting springs are seldom justified. The spring is too stiff if a relatively small longitudinal movement of the adjusting screw gives rise to a very considerable change of delivery pressure.

7. The number of joints at which gas leaks might develop as a result of careless assembly or through long usage should be reduced to the absolute minimum.

8. Cylinder regulators for use with high-pressure gas should preferably be constructed in such a manner that it is not necessary to break a high-pressure joint in order to replace the regulator seat, and in compound regulators the best arrangement is a regulator which requires the opening of only one pressure joint in order to reach both regulator seats.

9. A highly efficient dust filter is virtually required in cylinder regulators if the regulator is to be serviceable over long periods.

10. Proper seat accommodating and seat alignment means are desirable in cylinder regulators.

11. Adequate but not excessive damping is highly desirable.

12. In general, high-grade rubber diaphragms with strong fabric reinforcing insertion are greatly superior to metallic diaphragms.

(*a*) The stiffness of metallic diaphragms when assembled into a regulator with diaphragm plate in place is usually excessive. In many regulators of this type a slight yielding of the regulator seat will result in enough loss of stress to cause the regulator to leak when the adjusting screw is released. Excessive stiffness also results in inferior regulating characteristics.

(*b*) A high-grade fabric reinforced rubber diaphragm will last for at least ten or fifteen years. The fatigue life of metal diaphragms capable of permitting adequate seat displacement is relatively short.

(*c*) The joint between a rubber diaphragm and the regulator body is easier to make up tight than is the joint between a metal diaphragm and a regulator body.

(*d*) Unless the metal diaphragm assembly is permitted to be exceedingly stiff, it is possible to use a larger diaphragm plate with a rubber diaphragm than it is with a metal diaphragm; regulation is accordingly superior.

13. Oxygen regulators should be reliably protected against seat ignition.

14. A pressure relief, preferably of the relief valve type, should be employed on all regulators which are designed to handle compressed gases of pressures greater than 300 or 400 lb. per sq. in.

15. Only strong forgings or equally strong structural shapes should be employed for the regulator body and spring case.

16. All parts should be as ruggedly constructed as the practical requirements of the oxyacetylene welding art demand. Ruggedness and sensitiveness are not inconsistent.

Testing

Both in the selection and in the proper maintenance of regulators it is desirable to have a working knowledge of the more important performance tests, particularly those tests which can readily be conducted without an elaborate set-up.

One of the most important of these is a rough check of fundamental regulation and of end-point. If the regulator is a line regulator, this may be done by attaching the regulator to a line from a cylinder regulator and with a typical torch and tip connected to the regulator by a suitable hose line, varying the inlet pressure as delivered by the cylinder regulator throughout the range which would be encountered in practice. In order that the discharge through the regulator closely approximate the practical demand, it usually is essential that both the oxygen and the fuel gas be flowing through the tip at the same time. The effect of the inlet variations upon delivery pressure may then be directly observed. By continuously decreasing the inlet pressure, it will be possible to determine the regulation end-point by observing the point at which the delivery pressure begins to vary almost as much as the inlet pressure.

With cylinder regulators the general principles of the test just described are also applicable, but in this case the regulator must be supplied with gas at cylinder pressures. The regulator with hose and torch attached may be directly attached to a full cylinder and after adjusting the delivery pressure to the proper valve with the gas discharging through torch and tip, the cylinder valve may be suddenly closed. By closely watching both the low-pressure gage and the high-pressure gage it will be possible to note the approximate relationship between the delivery pressure and the inlet pressure. If the rate of out-flow is very large, however, it is frequently desirable for the sake of increased precision of observation, to include a high-pressure manifold bar, or other piping definitely known to be capable of withstanding the maximum cylinder pressure between the cylinder valve and the regulator. The increased reserve volume thus available after the cylinder valve has been closed will prevent the pressures from falling too fast to be accurately observed.

If the regulator is to be used for low out-flows, one should not in selecting a regulator, omit a low out-flow test similar to the one just described except that the regulator should have been idle before the test for at least an hour with the adjusting-screw released and

without being subjected to gas pressure by being attached to a cylinder. In this test, moreover, the cylinder valve should not be closed. The regulator should be quickly adjusted to the proper delivery pressure with torch and small tip attached, and the delivery pressure noted from time to time for the first half hour, during which time the regulator naturally is not to be readjusted.

The static increment and creep, of course, may be observed by closing off the torch valve while the cylinder valve is still open. For full information as to the static increment characteristics of a regulator, it is desirable that this test be conducted at several different cylinder pressures between full cylinder pressure and the regulation end-point. It is worth observing, however, that the significance of the static increment test frequently has been overrated. A regulator with abnormally high static increment compared with others of its class is to be considered doubtful, but there are few cases where a static increment less than 1 or 2 lb. in a welding regulator or 8 or 10 lb. in a cutting regulator is essential in actual practice.

The efficiency of the filter can be tested by pouring clean fine sand or metal filings *free from oil or dirt* into the inlet of a sample regulator, and then attempting to use the regulator by alternatively opening and closing the torch needle valve after the regulator has been adjusted to a typical delivery pressure.

In testing a regulator the adjusting-screw should never be turned in when the regulator is attached to a source of gas supply unless hose, torch and proper tip (or their equivalent) are connected to the regulator outlet. Regulators, if carefully designed, are provided with damping adequate for only the maximum out-flow which will be encountered under practical conditions. They are not intended to be used with the outlet wide open.

Elaborate or dangerous tests, such as seat-ignition tests and hydrostatic tests of regulator bodies or diaphragms, should be avoided unless detailed instruction is secured directly from the manufacturer.

Care and Use

The first consideration in the use of regulators is, as previously intimated, to use the right regulator for the particular application and to use it in the proper manner. This almost trite observation is extremely important but is frequently violated. Of course, it is not always entirely obvious as to when a regulator is used in the proper manner, but the discussion in these pages should do much to make this clear. Some miscellaneous considerations, however, may profitably be introduced at this point.

One of the most important of these is that the working pressure range of a cutting or manifold regulator is exceeded if with increasing adjustment with the outlet of the regulator closed a point is reached at which a relatively small turn of the adjusting-screw gives rise to a very considerable increase in delivery pressure.

The working range of any line regulator is exceeded if with proper torch and tip attached further turning of the adjusting-screw does not give rise to further increase in delivery pressure. There should preferably be at least a 2- or 3-lb. margin between the normal delivery pressure of a welding line regulator and the maximum delivery pressure which can be obtained in the manner just described. Of course, if the working range does not exceed the normal delivery pressure, it may be no fault of the regulator. It may be due to the operator having insisted on a higher delivery pressure than he actually requires. In fact he may have throttled this pressure down to a more reasonable value through the use of the needle valve on his torch. Or it may be that the delivery pressure is correct but the line pressure is entirely too low. When regulators are misused in this manner they do not function satisfactorily as back pressure cut-off valves in event of flash-backs or the counter flow of another gas.

It is helpful to know that most regulators give slightly better results if the delivery pressure is reached by a clock-wise turning of the adjusting-screw instead of dropping back from a somewhat higher pressure following a careless preliminary adjustment.

Of course, it is essential that the regulator be not opened and tampered with out of mere curiosity or in the belief that indiscriminate replacement of regulator parts will improve its performance.

No unauthorized or unqualified person should be entrusted to make regulator repairs.

Finally, let it be emphasized that the manufacturer is generally well qualified to advise on regulator problems and to assist the user in getting the optimum performance. Where there is the slightest doubt, the manufacturer should be consulted.

Membership Drive

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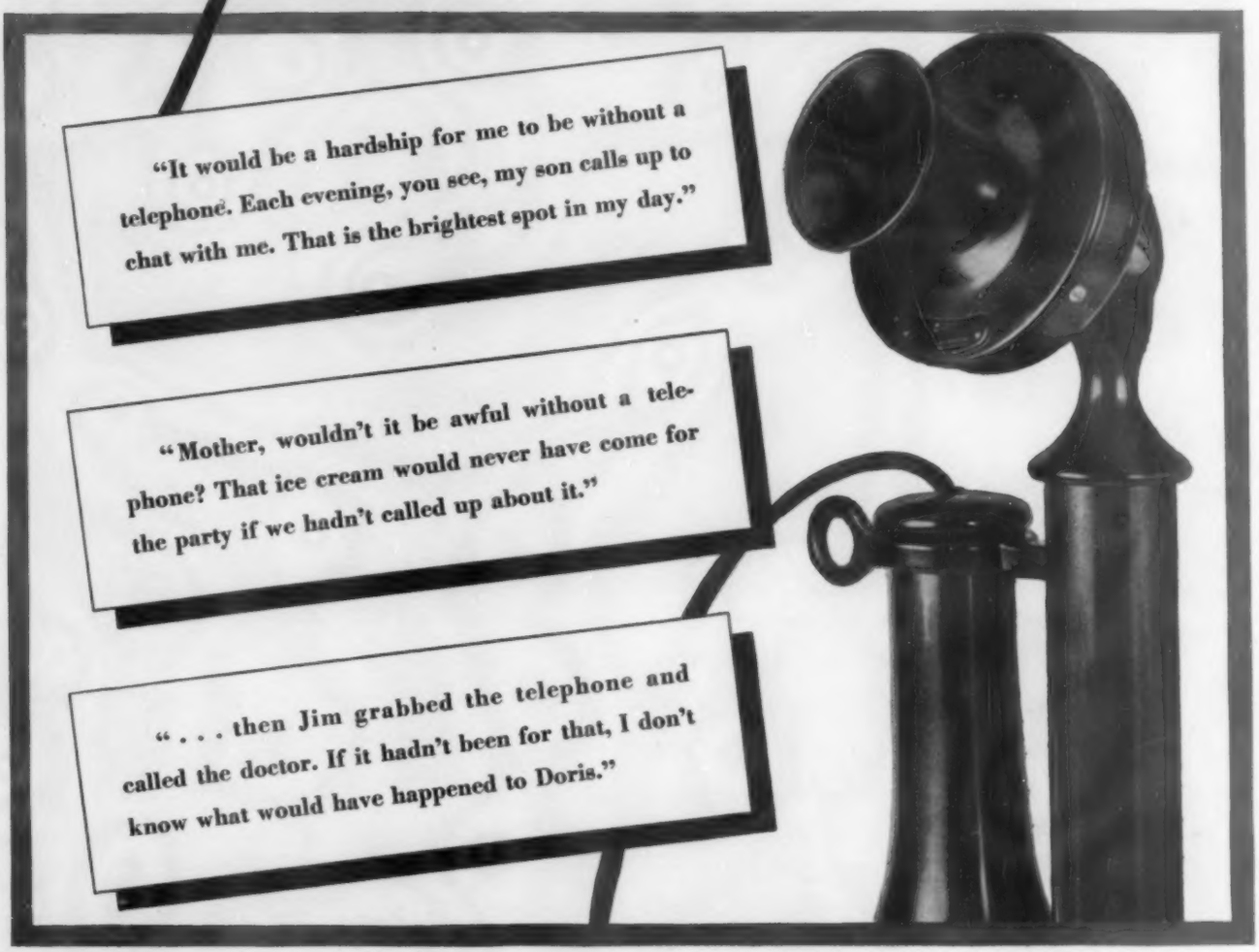
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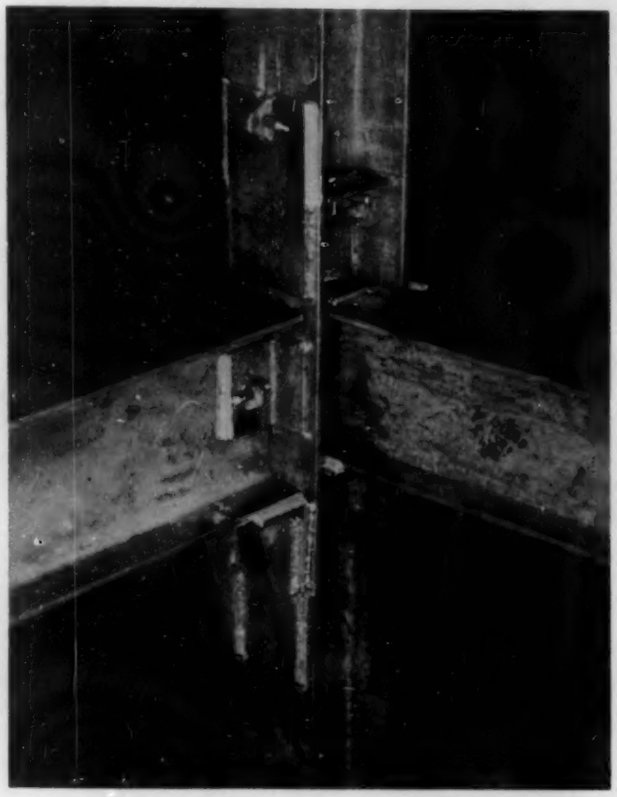

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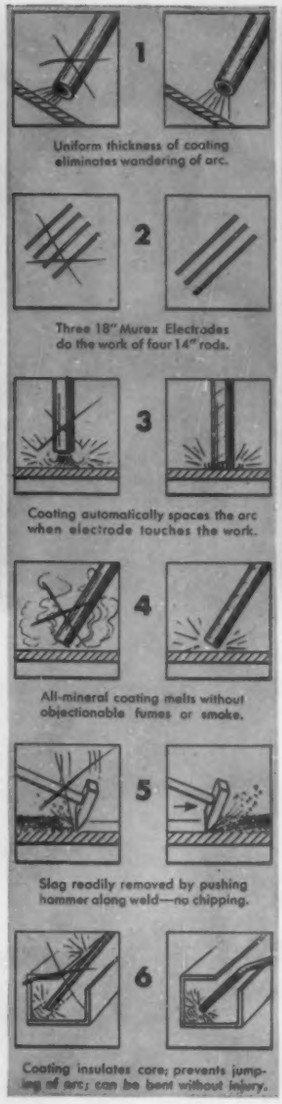
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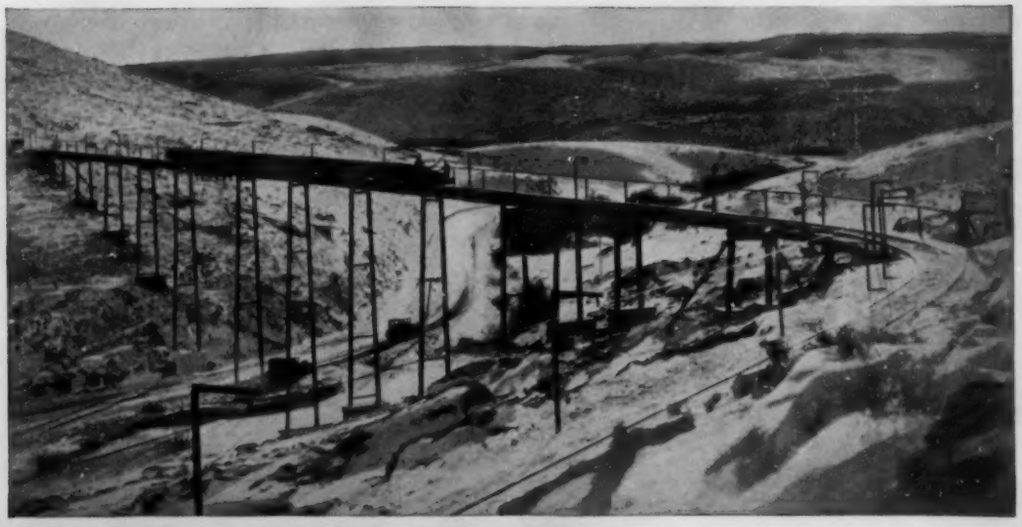

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